a Feasibility Study for Transitioning Louisville, Kentucky's Transportation and Electricity Generation to Renewable Sources

Citation

Darst, Timothy. 2016. a Feasibility Study for Transitioning Louisville, Kentucky's Transportation and Electricity Generation to Renewable Sources. Master's thesis, Harvard Extension School.

A Feasibility Study for Transitioning Louisville, Kentucky's Transportation and Electricity Generation to Renewable Sources

Timothy J. Darst

A Thesis in the Field of Sustainability and Environmental Management
for the Degree of Liberal Arts in Extension Studies

Harvard University

May 2016

Abstract

Climate change is caused mainly by humans and there is a great risk of "severe, pervasive and irreversible impacts for people and ecosystems" (IPCC, 2014). It has been proposed by many that America can address climate change by simply buying electric cars and then obtaining all electricity from renewable sources (Deutch, & Moniz, 2010; Freeman & Parks, 2016). This "silver bullet" is appealing; however, without detailed study it is not known whether this is a viable solution in many communities across the United States. Louisville, Kentucky was chosen as a case study to determine if it is feasible for conversion to a 100%-renewably-sourced electricity grid and all-electric transportation model. Louisville is in one of the largest coal producing states, is heavily dependent on coal for electricity production, and has a high per capita number of vehicle miles driven annually. In this study the amount of energy needed to power all of the city's vehicles using electricity was measured, and the amount of electricity that the community would be able to produce from renewable energy sources was estimated.

The results indicate that while still monumental in cost and scope, it is possible to convert Louisville's electricity grid to 100% renewable energy while replacing all of its vehicles with electric vehicles by 2050. To reduce the cost and magnitude of this conversion, conservation and efficiency measures are needed that result in a 26.5% decrease in electricity and a 15.6% reduction in transportation by 2050. Hydroelectricity, wind energy, electricity produced from biomass, and energy storage can meet nighttime base load demand and provide the dispatchability needed for grid stability. After

conservation and efficiency and producing energy from other renewable sources, this conversion would require more than 48 million solar panels, enough to cover 36.5 square miles or 9.1% of the city. A transformation of this magnitude will require a large commitment from the community and full participation of the governmental, business, and non-profit sectors.

Acknowledgements

Many thanks to those who helped me along the way in my research and writing, listed here alphabetically, Stacy Bogan, Junior GIS Specialist at the Harvard Center for Geographic Analysis for help in learning to work with GIS data, Dr. Kate Bulinski, Associate Professor of Geoscience at Bellarmine University’s School of Environmental Studies, for taking on the difficult task of being my thesis director, Andrea Chaves, business technology analyst at Deloitte Consulting LLP in Denver for help with the LiDAR data and ArcGIS programs, George Clark, research librarian at Harvard’s Lamont Library for help in researching and finding documents, Sarah Lynn Cunningham, Executive Director of the Louisville Climate Action Network for technical consulting, Susan Dresley, librarian at the U. S. Department of Transportation Volpe Library for her help in finding sources, Philip Gerstein, librarian at the Harvard University Godfrey Lowell Cabot Library for assisting me in research, Geoffrey Hobin, Capital Program Administrator for the Transit Authority of River City for help with finding transit data, Matthew Jolly, for his work using GIS and LiDAR data, Lori Kelsey, transportation planner at KIPDA for her help in finding census data, Mark Leighton, Harvard University’s Extension School for advising me for this thesis, my wife Angela Lincoln, for being patient with me and being understanding about the many hours of work that was needed for this research, Doc Manning ,for help in understanding the complexities of electricity production, Randy Simon, transportation planner at KIPDA for help in

locating data, Elizabeth Youngblood, for pointing me to sources about solar energy, and Barry Zalph, for proofing and giving me advice on research.

Table of Contents

List of Tables

List of Figures

Definition of Terms

Base load: Utilities use certain sources of electricity to provide a consistent level of electricity that does not fluctuate throughout the day or night. This minimum amount of electricity is necessary to meet the basic electricity demand of the customers. This demand is called the base load.

Bioenergy: Energy produced from plants, such as the electricity and or heat from burning wood, or the energy produced from burning ethanol, or the heat or electricity produced from burning landfill gas.

Efficiency: For the purposes of this research, efficiency is the reduction in use of electricity that is achieved by a change in the technology to perform the same task while using less energy. An example of this would be changing to a car that has greater miles per gallon (MPG) or miles per gallon equivalent (MPGe).

Grid: All cities in North America are connected with a series of electrical connections that allow for energy production facilities to reach energy consumers. These connections that involve power plants, high-voltage lines, substations, distribution lines and consumers are commonly referred to as the grid.

Hub height: The distance from the ground or platform to the rotor of an installed wind turbine as an indication of how high a turbine stands. The hub height should be based on prevailing winds at various heights in order to harvest the optimum amount of wind energy for that location.

Nameplate capacity: The maximum about of energy a power plant is rated to produce, usually expressed in megawatts (MW).

Net generation: The gross amount of electricity generated at a plant less the amount of electricity used at the plant.

Operating reserve: The additional electricity generating capacity that is available for use by a utility on a moment's notice in case demand increases or supply drops.

P2G: The conversion of power to gas as a form of storage principally accomplished using electricity to convert water to hydrogen through electrolysis.

Peak load: This is the maximum amount of electricity needed for customers for a time period. Additional electricity production is brought on line to meet this peak demand or it is purchased from other producers on the grid.

Renewable energy: Renewable energy is any energy source that does not require millennia to regenerate as in the case of fossil fuels like coal, oil, and natural gas and nuclear energy. Renewable energy typically comes from the sun, wind, water, and heat from the core of the earth.

V2G: Vehicles to grid describes the ability of batteries in vehicles to power the electrical grid by allowing for the flow of stored energy backwards from the vehicles to the grid.

Chapter I

Introduction

Transportation and electricity generation make up a significant portion of total carbon emissions that cause climate change (EPA, 2015). Finding alternative solutions for these two sectors would be important in order to reduce overall greenhouse gases. For Louisville to make this transition, the community must know what is possible and what options are available in the region. Because Louisville has a heavy reliance on fossil fuels for electricity generation, simply converting the transportation fleet from fossil-fuel-based to electricity-based will not mitigate climate change (Deutch, & Moniz, 2010; Tessum, Hill, & Marshall, 2014). A conversion of power-generation to a renewable electricity mix is also essential. Transportation is particularly difficult to address because Americans have a love affair with their cars (Hsu, 2012). Those using alternative modes of transportation like public transit, bicycling and walking remain a small percentage of commuters (Taylor & Fink, 2003; McKenzie, 2014). Generous subsidies make petroleum the fuel of choice for most Americans (Morales, 2014).

Research Significance and Objectives

While there has been much published on the importance of reducing carbon emissions and moving to more sustainable electricity generation and transportation, a feasibility study for making this conversion has never been done specifically for a city. In order for Louisville to address these major sources of greenhouse gas emissions by tapping local resources, this comprehensive study is needed. Beyond sweeping generalizations, no study has examined the feasibility of both converting vehicles to electricity and switching to 100% renewable electricity production on a city-wide scale.

The objectives of this study are threefold. First, it is necessary to get a better understanding of what is needed to replace Louisville's transportation fleet with vehicles that run on electricity. This would include an examination of issues such as increased traffic on the electricity grid, the infrastructure needed for charging vehicles, the timing of that charging as it pertains to peaks in demand, and the pace at which a transition would be manageable.

The second objective of this study is to determine what renewable energy options are available to Louisville and their level of feasibility. The issues that are part of this research include the intermittency of renewable energy sources, their lack of dispatchability, and their limits based on location. The final objective of this study is to provide a comprehensive analysis of the options for city leaders to consider when addressing this conversion of transportation and electricity generation sectors in Louisville, Kentucky.

Background

When urban communities are faced with the task of eliminating their carbon emissions as a response to global climate disruption, they have little research to turn to in order to find concrete steps as to how to realistically accomplish this. That being said, there are many resources for making energy efficiency improvements and conservation in the various components of a city. For instance, there are plenty of known strategies for reducing energy use in buildings or decreasing emissions from vehicles. Numerous studies have suggested that the most effective solution would be to convert vehicles to electricity and then convert the generators of that electricity to lower carbon sources (Kepton & Tomic, 2005; Kempton & Letendre, 1997; Liu, Chau, Wu, & Gao, 2013; Delmas, Kahn, & Locke, 2014), but, to date, no feasibility studies have been done on the scale of a city. Three American cities have been able to acquire 100% of their electricity use from renewable sources, Aspen, Colorado, Burlington, Vermont, and Greensburg, Kansas, but these cities still power their vehicles with gasoline and purchase renewable electricity from outside of their area.

There are 100% renewable energy studies performed on the scale of a state and few performed on the scale of a nation (Jacobson, et al., 2014; Wei, et al., 2013; Jacobson, et al., 2013; Jacobson, 2014b; Jacobson and Delucchi, 2009; Delucchi and Jacobson, 2011; Jacobson and Delucchi, 2011; Watson, Gyenes, & Armstrong, 1986; SRU, 2010; Jacobson, et al., 2014a). These studies do not assess the ability of variable generation to meet actual hourly demand within a transmission region according to Budischak et al. (2012). These national and global plans are also on a scale too large to be used as a roadmap for a city. Plans for states like California and New York are not useful for most other U. S. states with a high dependence on coal since California and New York have access to coastal energy resources (e.g. off-shore wind, tidal energy, wave energy, etc.). Jacobson and Delucchi, the authors of many of these studies, admit that they have not done extensive research on the specific strategies needed to implement the plans (Jacobson, et al., 2014a). State-wide plans are also not as customizable as city-wide plans, because the public policies and mechanics for utilities and transportation are much more manageable on a local level.

City-wide “climate action plans”, while very common around the country, are not intended to be viability studies or road maps to 100% alternative energy conversion. Almost every major city has one of these plans but most of these merely set goals of a certain percentage reduction in carbon emission by a certain date (U. S Environmental Protection Agency, 2015). These plans do not calculate the specific electricity capacity needed to produce 100% of the energy from locally sourced renewable sources (U. S Environmental Protection Agency (2015). Budischak et al. (2012) performed a true viability study of renewable energy and storage on a regional scale covering parts of 13 eastern U.S. states and show that wind and solar combined are technically and economically viable source of energy 99.9% of the time, but they require fossil fuel backup systems and large geographical expansion. Because of the use of fossil fuels in their study, their plan does not qualify as a 100%-renewable energy study. Freeman and Parks (2016) examined the city of Los Angeles and discussed the strategies that would facilitate a 100% conversion of the vehicles and grid. This example is a simplified version of a city plan, but since Los Angeles is in California, a state that has already made large steps towards renewable energy and electric cars, is not as helpful for most cities in the U.S.

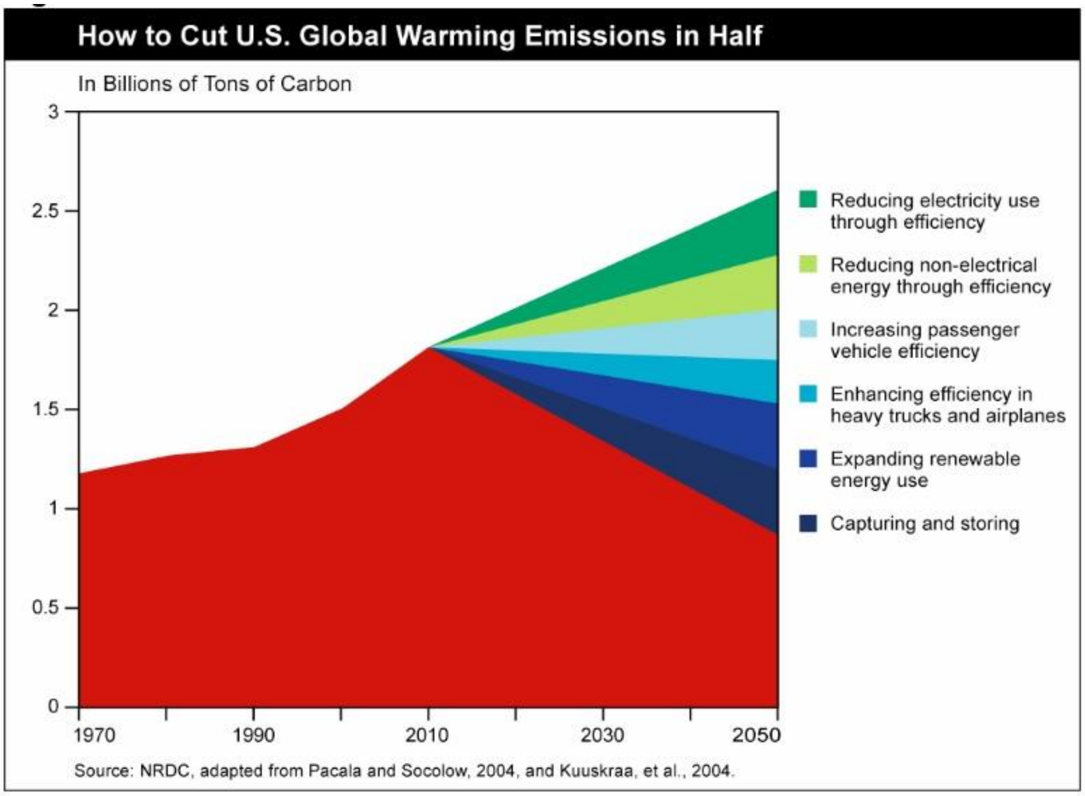


Fig. 1. How to cut U. S. global warming emissions in half (Source: NRDC, 2005).

Other research on the topic of carbon reductions comes from Pacala and Socolow (2004) who concluded that there must be a multifaceted approach due to the lack of a silver bullet solution and that it will likely include: efficiency and conservation, reduced reliance on cars, more efficient buildings, electricity generation efficiency, replacing coal plants with natural gas plants, carbon capture and sequestration, wind energy, biofuels, solar energy, among other solutions. They refer to these as “stabilizing wedges” where each of these wedges reduces carbon emissions (Figure 1). U.S. carbon emissions missions (Figure 1) are projected to grow to about 2.5 billion tons by 2050. The green and blue wedges represent the various strategies (“wedges”) that could reduce emissions in the aggregate to less than 1 billion by 2050. While their conclusions appear sound, their research does not include the specific steps that would be needed to accomplish this. Each city will have to examine the many options available and tailor conversion efforts to specific local circumstances.

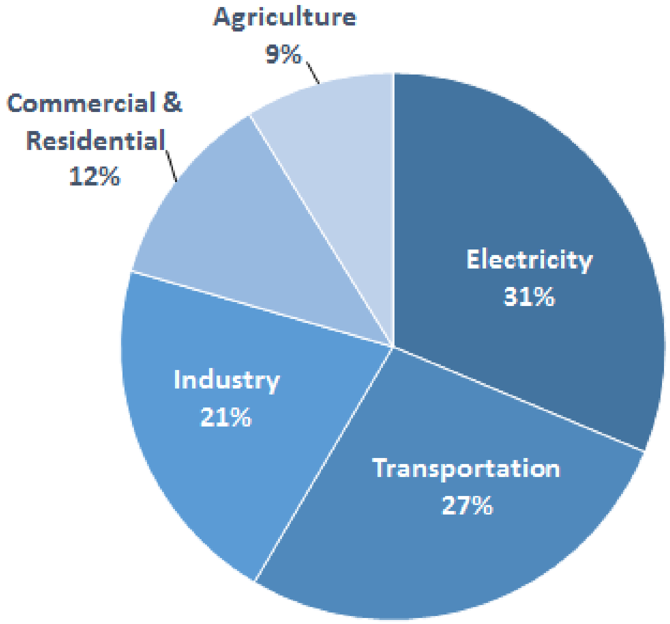


Fig. 2. Sources of greenhouse gas emissions (EPA, 2015).

It is crucial to eventually get to a 100%-renewably-generated electricity grid. If it is necessary to reduce the ambient levels of greenhouse gases in the atmosphere in order to stabilize the climate, then simply reducing emissions will not fully achieve that goal. Reducing emissions lowers the amount of greenhouse gases that are adding to the atmosphere, it does not reduce the amount of greenhouse gases that are already in the atmosphere. Still producing greenhouse gases, is still adding to the problem. As Inman (2008) points out, carbon released into the atmosphere is there “forever.” Meaning that carbon that was safely sequestered deep beneath the earth was long ago taken out of the carbon cycle and extracting and burning fossil fuels simply adds more carbon to the carbon cycle that will remain in the atmosphere for millennia. The aim of this study to is to determine how to reduce transportation and electricity generation emissions to zero, acknowledging that there are other sectors that will still have emissions. For this reason, it is even more important to achieve zero emissions from the two largest sectors of transportation and energy generation which account for 58% of total U.S. greenhouse gas emissions (Figure 2). The Intergovernmental Panel on Climate Change (IPCC, 2014) has indicated that industrialized nations will need to reduce their greenhouse gas emissions by 40 to 70 percent below 2010 levels by 2050 in order to limit global warming to 2 °C. Mai, Sandor, Wiser, & Schneider (2012a) performed a detailed analysis of electricity generation resources and determined that renewable energy resources could adequately supply 80% of total U.S. electricity generation in 2050 while still balancing supply and demand at the hourly level. One of their scenarios assumed that 40% of the passenger transportation fleet transitions to electric vehicles by 2050 (Mai et al., 2012b). Even though their calculations did not include transition to 100% electric vehicles nor did they project a 100% renewable energy portfolio, their analysis does help to address many of the issues involved in a high renewable scenario like energy storage and the intermittency of wind and solar. The 100% renewable energy/electric vehicle scenario presented in this study includes these considerations and more.

Base Load and Peaks: Balancing Demand and Supply

There are a number of factors that will make conversion to renewable energy and the addition of electric vehicles to the grid difficult for Louisville and therefore must be addressed (Mai et al., 2012a; Augustine, 2012; Mai et al., 2012b). Unlike most commodities that are manufactured and stored away until sold, electricity must be created at the time that it is used (Smithsonian Institute, n.d.). Grid operators at Louisville Gas and Electric Company (LG&E) work constantly to balance supply and demand. In order to avoid disruptions in the balance, efforts are made to predict the demand (Callaway & Hiskens, 2011). LG&E communicates with industrial customers who have large electricity demand in order to know when they will be powering up their equipment. Many commercial users start turning on lights and equipment at about the same time that many people are waking up and turning on their lights, toasters, blow dryers, ovens, and other appliances. This creates a morning peak in demand that the utility tries to anticipate (Figure 3). This peak extends into the early evening since many businesses and factories are still operating while citizens are using electricity at home (Callaway & Hiskens, 2011).

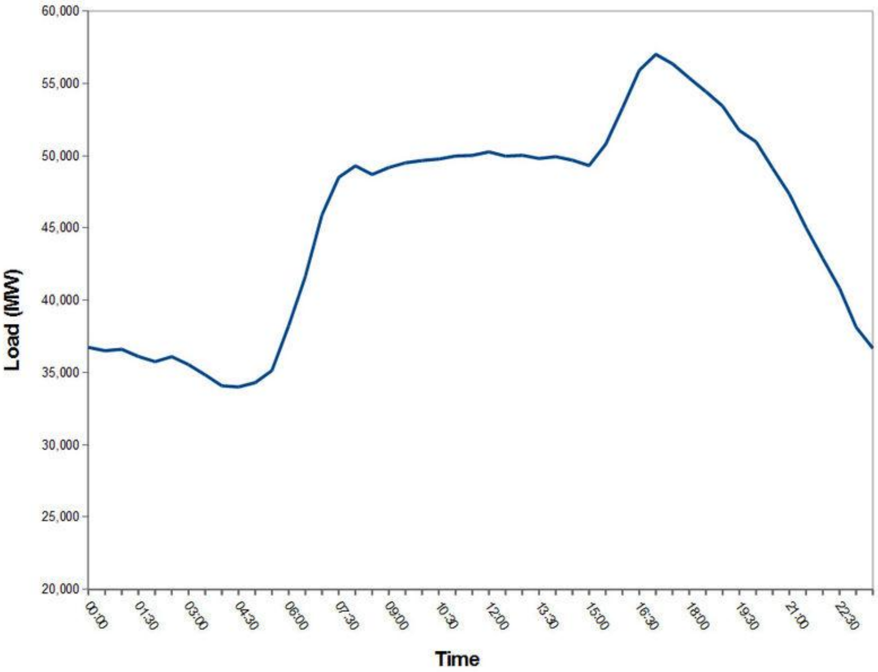


Fig. 3. Hourly electricity demand. (Source National Grid, n.d.).

Utilities like LG&E also use historical data and weather predictions to determine when the bulk of their customers will be using air conditioners, space heaters, or other similar devices. A peak occurs in the summer, usually during the month of August, because of the large number of air conditioners that consume a large amount of electricity (Callaway & Hiskens, 2011). In areas serviced by LG&E's sister company, Kentucky Utilities, many electric heaters are used resulting in a winter peak, usually in January or February. To accommodate these fluctuations, utilities have the ability to decrease their production of electricity to avoid too much of a surplus, or increase their production to meet demand. Many power plants have multiple generators that they can either power down or turn off entirely. Even when demand is low, utilities are required to keep generators on line, or ready to bring on line, in case there are increases in demand or other generators fail. Utilities currently maintain a 15-20% reserve (Freeman & Parks, 2016). The potential energy from these generators that is available, but currently not in use, is referred to as the operating reserve. Spinning reserves consist of generators that can start immediately and non-spinning reserves are sources that can start within minutes (Callaway & Hiskens, 2011). There are, of course, limits to how much a power plant can produce and how many reserve generators the utility has available to meet the demand on a moment's notice. Off-line coal plants take days or weeks to power up and become fully operational, while natural gas plants can be turned on more quickly.

There are differences in the way that renewable and non-renewable sources generate electricity. For instance, fossil fuels energy can be generated when needed and provide a consistent predictable base load for electricity production (Callaway & Hiskens, 2011). Wind and solar are harvested and fluctuate with the amount of wind and sunlight available at any given time. Hydroelectric power can typically be generated when needed, but may also be subject to the amount of water available based on the type of hydroelectric plant. With any type of electricity production, if demand for electricity is greater than the supply at any point, electricity is usually purchased from utilities in other regions. This practice is crucial so that utilities can meet the demand of its customers at any given time of the day, thus avoiding brownouts or blackouts that could cause data loss or equipment damage (Lee, 2014). As a result, utilities require constant monitoring of demand and production and require continuous fine-tuning to get supply and demand to balance. Once Louisville's renewable energy production approaches about 50% of supply, fluctuations in supply could destabilize the grid (Martin & Crawford, 2015). Sufficient storage of electricity and extra capacity will have to be added to the grid to maintain stability in a 100% renewable energy future (Freeman & Parks, 2016).

Ramping

In times of increased demand LG&E must ramp up electricity production. This usually occurs in the morning when businesses and homes power devices that require energy and in the evening when power is again used in homes. This pattern will change as more solar capacity is added. As solar energy during the day increases, LG&E will need to ramp down their combustion sources. Then in the early evening, when the sun starts to set and the evening peak is starting, ramping up energy sources from fossil fuels is needed to make up for the shortfall. Projected hourly demand (Figure 4, blue) for electricity on a typical day in 2020 when solar penetration is expected to be greater. The morning peak starts around the 5th hour (5 a.m.) and the evening peak around the 16th hour (4 p.m.). The demand is reduced by the production of electricity from wind and solar so the net demand (Figure 4, red) shows a sag in the middle of the day. This combination graph is often referred to as "the Duck Curve" because it resembles a duck (Lazar, 2014). As the amount of solar and wind power on the grid increases, this ramping up and ramping down between electricity sources becomes more dramatic. This ramping can be a challenge because it causes additional wear and tear on the power plant equipment and because of the difficulties involved in planning and forecasting the timing of the ramps.

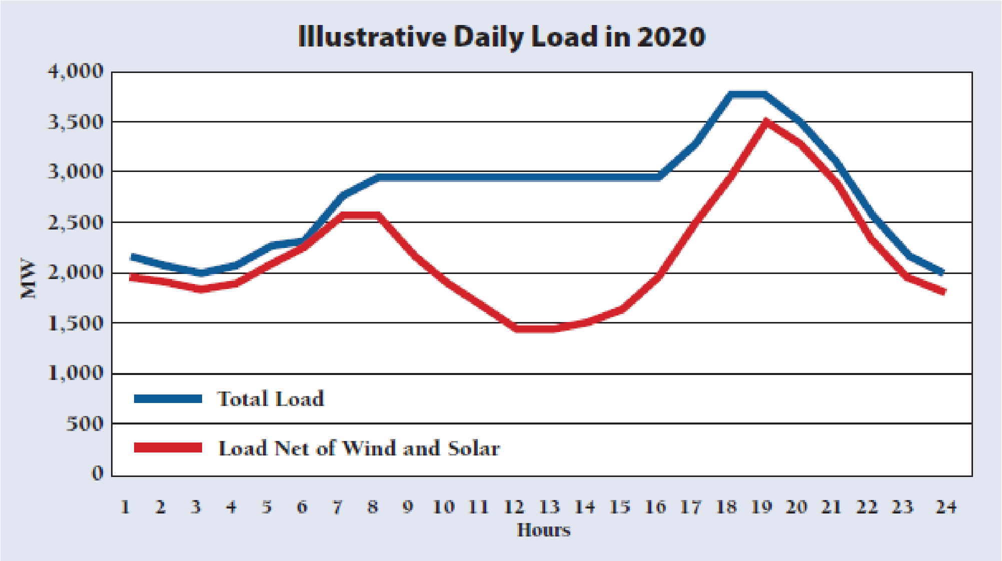


Fig. 4. Illustrative daily load in 2020 (Lazar, 2014). "Total load" is the amount of electricity to be generated to meet demand and "load net of wind and solar" is the amount of electricity generated reduced by the about of wind and solar generated.

Surplus Energy

Providing too much energy can create the same problems for the grid as too little energy, e.g. blackouts and brownouts (Fuchs, 2011). Because renewable energy sources like wind, hydro, and solar have fluctuations that are out of the utility's control sometimes they produce too much electricity. Much of this fluctuation is predictable and can be planned for using meteorological data. Sophisticated weather predictions help a utility anticipate how much electricity that wind turbines, hydro plants, and solar panels can produce during a span of time (SAS Institute, n.d.). When the sun is shining, wind is blowing, and water is flowing, utilities must store or export the surplus, or curtail its production. Too much electricity on the grid can lead to congestion due to the limitations on transmission forcing utilities to curtail production. Mai, et al. (2012a) estimated that 8%–10% of wind, solar, and hydropower generation would need to be curtailed under an 80%-by-2050 renewable energy scenario. They further point out that curtailments reduce capacity factors, have an adverse effect on prices for electricity, and a negative impact the profitability of a plant (Mai, et al., 2012a). This makes those renewable assets less financially viable. In times where there is too much energy available because of ample solar and wind, it would seem logical to cut back on fossil fuel combustion plant generation because this would save the cost of the fuel. This, however, is not always practical because of the difficulty and time required to take combustion generators off line.

EV Charging

Granade et al. (2009) acknowledge that “electric vehicles hold the potential to offer U.S. consumers a practical alternative to gasoline-powered vehicles by 2020” (p. 108). “Economic, security, and environmental pressures are driving counties around the world to electrify transportation” according to Silver Spring Networks (2013, p.2). According to Kirchner (2008), electric cars “consume about four times the electricity as plasma TVs” (p. 50) and the utility industry has already had to adjust to the added demand from millions of plasma televisions that Americans purchased over the past decade. He quotes an industry official that “as long as the changeover from internal combustion engines to electric is somewhat gradual, they should be able to handle it in the same way” that they did the plasma televisions. Since a large conversion is needed quickly to avert catastrophic climate change, a gradual change will not be sufficient and utilities must be ready for the increase in demand. As customers change their habits and their electricity usage increases or decreases accordingly, LG&E must adapt. One example of a change in demand involves the introduction of electric vehicles into households. U.S. electric vehicle sales increased by 128% between 2012 and 2014 (Grier, 2015). According to Silver Spring Networks (2013), a company that specializes in smart grid technologies, the electrical load of a level 2 charger (L2) for an electric vehicle is comparable to that of an air-conditioned house (6.6kW for an L2 and 7kW for a house). The company says that “electric vehicles will fundamentally change how electric utilities do business and strain their existing infrastructure” (Silver Spring Networks, 2013, p. 1). In addition, the EV manufacturer Tesla has been installing 120kW level 3 chargers in parking lots of retail stores around the country adding even more demand (Linden, 2015, Tesla, n.d.c). The increased load due to charging EVs can cause a number of problems such as overloading transformers and exceeding the load capacity of the utility.

The addition of L2 chargers could overload the capacity of a neighborhood transformer (Figure 5). Additional capacity is currently built into the existing grid to accommodate increases in load, but huge increases caused by L2 charges could quickly exceed the capacity of the transformer. Overloading the transformer causes an increase of operation temperature that accelerates the aging of the equipment and can lead to failures (Rashid, 2011). As the number of EVs increases and level 2 chargers are added to the grid, utilities will have to adjust the infrastructure to accommodate the increased load.

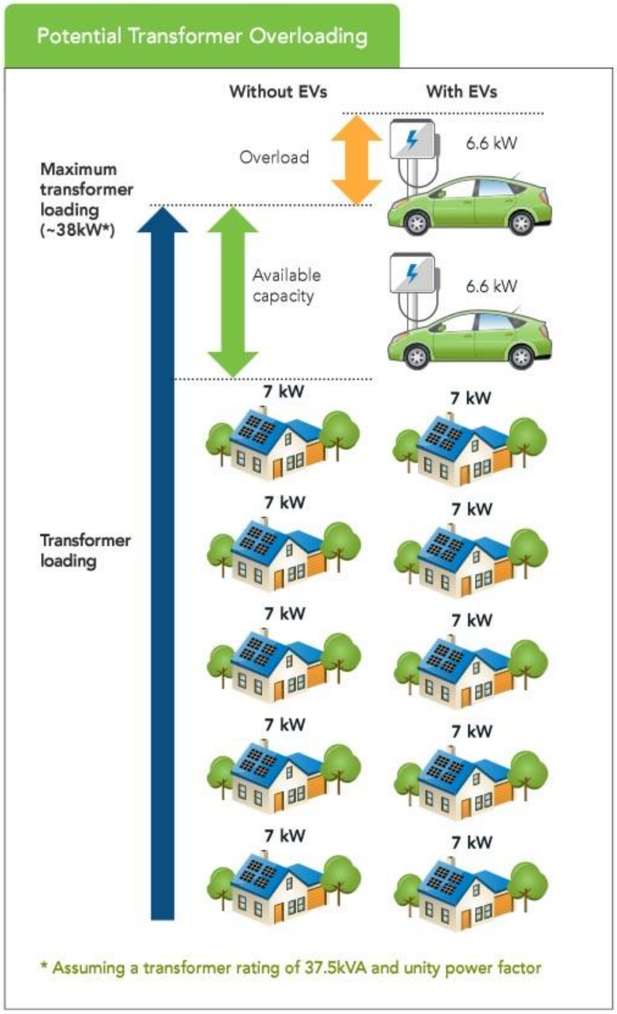


Fig. 5. Potential transformer overloading due to L2 EV charging (Silver Springs Network, 2013).

Currently most EV owners are charging their vehicles at home using standard electrical outlets and voltage. Increasing penetration by EVs is already leading to more charging stations around the country to reduce "range anxiety" on the part of the owners (Scanlan, 2015). More charging stations in various locations will be needed for consumers to overcome range anxiety before the majority of the population purchases EVs. Since standard electrical outlets take a long time to charge an EV battery, these charging stations need to be equipped with higher level chargers that allow for shorter charging times.

Currently many electric vehicle owners charge their vehicles in the evening. This is not currently problematic because there are so few EV owners (Grier, 2015) and charging at night prevents consumption of energy during peak demand periods. Hostick et al. (2012) cited studies that predict 74% of PEV users are expected to charge their vehicles at night. Su, et al. (2014) noted that EV charging will drive up the peak demand and may cause grid instability. According to Kirchner (2008), outside of the peak periods, most utilities have excess generating capacity at night that could be used to recharge cars since most electric cars will likely be charged then, and conclude that utilities should have no problem generating enough electricity. This is because most utilities, like LG&E, use fossil fuels, principally coal and natural gas, to produce base load energy and they have excess capacity at night to meet the demand for recharging a limited number of vehicles. However, problems will arise when LG&E makes the conversion to renewable sources. If the grid is heavily reliant on solar energy in the transition away from the traditional base load sources of coal and natural gas, then the utility will not have the excess capacity at night as before. According to Granade et al. (2009) even at low levels of market penetration, electric vehicles will pose a challenge to the grid because of increases to peak demand, and recommend that local utilities undergo localized energy assessments to determine if the generating capacity will be able to meet the increased demand (Granade et al., 2009). They estimate that although generation capacity during non-peak hours could accommodate electrification of up to 73% of the current vehicle population, vehicle charging would have to be timed to avoid peak usage;

otherwise, additional generating capacity will be needed (Granade et al., 2009). Chan, Jian, and Tu (2014) claim that as penetration by PEVs increases, the greater demand will "definitely trigger extreme surges in demand" and "threaten the stability and security of the power grid (p. 2)." As the number of EVs increases, LG&E will have to monitor when they are being charged and adapt accordingly. If this creates a new peak in demand, or intensifies energy requirements during an existing peak, then sources of electricity will be needed to meet that peak.

Of the three levels of charging for EVs, level 1 chargers use the basic household 110-volt outlet. Level 2 chargers can provide 240 volts and reduce charging time in half, but they double the load on the grid (Saxton, 2011). Level 3 chargers can provide from 400 to 600 volts. The Level 2 and 3 chargers, while posing the biggest peak threat, can also provide the best V2G options because of the amount of electricity they would be able to feed back to the grid. Hostick et al. (2012) envision three scenarios that will unfold over time with respect to EV charging and discharging through 2050. The first is involves no control on the part of the utilities and EV owners will charge whenever they want, typically when they get home at the end of the day. In the second scenario, there is an assumption that charging infrastructure is more prevalent and owners will charge whenever they have the opportunity. The third scenario is in a future where the percentage of renewable energy is high and PEVs are charged/used to store energy during the day and then discharged at night when solar energy is low (Hostick et al., 2012). As these scenarios unfold over the years (Figure 6) they will slowly flatten the peaks and fill the valleys. LG&E will likely need to implement a combination of these scenarios to avoid peak demand exceeding production capacity.

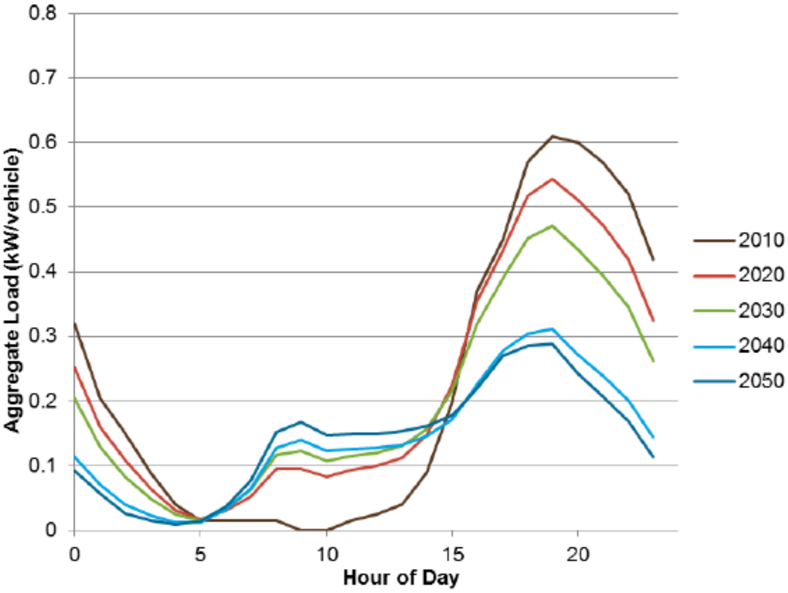


Fig. 6. Shape and transition of fixed hourly aggregate load profile for PEVs (Hostick et al. 2012, p. K-11).

Operating Reserves and Storage

LG&E must maintain additional electricity generating capacity that is available on a moment's notice in case demand increases or supply drops. These reserves take the form of natural gas combustion turbines at the company's smaller power plants. New sources of energy production will be needed to replace these generators in an all-renewable grid. Because of the greater variability issue, a larger amount of reserve capacity will be needed as well. This means that LG&E will need to have a larger investment in electricity generating assets than it has now. Some of these assets will certainly consist of storage facilities rather than generation facilities, a technology with which LG&E, like many utilities, currently has little or no experience.

Mai et al. (2012a) found the use of storage to be an attractive option to increase system flexibility due to shift load from periods of high demand, to address intermittency from variable sources, reduce curtailments by storing excess generation in times of low demand, and provide firm capacity for reserve. Firm capacity is the amount of energy available for production and transmission which can be guaranteed to be available at a given time (Energy Vortex, n.d.). Modeling performed by Mai et al. (2012a) project that about 10% of generating capacity must be derived from storage under their 85% renewable energy scenario. There are many storage options currently available LG&E that will need to be a part of the base load of the future. Those include: pumped storage in hydroelectric reservoirs, batteries in homes, batteries in EVs, utility scale batteries banks at power plants, compressed air, and fly wheels.

Some older power plants, like LG&E's Mill Creek and Trimble coal plants, must run continuously because of the time and expense required to start and keep them running. These facilities are designed to remain running all of the time, except for short periods for repairs or maintenance. This has not been a problem in the past since they were the main source of power and additional dispatchable sources could be used to meet peak demand. In a future with huge swings in energy production from intermittent sources like wind and solar, these must-run generators can become a liability as they would be producing electricity that is not needed. This will only pose a temporary problem, however, because once a 100% renewable grid is reached, these plants will be retired (Lazar, 2014).

Limitations for Renewable Energy Production

There are limitations on the amount of electricity Louisville can generate using only locally-sourced renewable energy. There is only so much usable roof space and sunlight for solar, only so much water for hydroelectricity and only so much wind or land space for wind turbines. If there are not enough locally-sourced renewable sources to meet the additional demand, other options like efficiency and conservation must be assessed and incorporated. Typically, conservation is the most cost-effective source of electricity savings and should be fully utilized before additional capacity is built. For example, it would not be prudent to construct an expensive power plant to generate electricity that it is not needed if additional conservation efforts could eliminate the need for the energy in the first place.

Solar energy is also limited to those hours of the day in which the sun is shining, and wind only to times where the wind is blowing, thus storage of energy would certainly have to be part of the solution to provide energy at night and on days without wind. Hydropower that relies on the flow of the river would be limited to those parts of the year when there is sufficient river current to move the turbines. Bioenergy and energy storage will be needed to supply electricity when solar and hydro cannot.

There are limits to the amount of materials available for use in the manufacturing of renewable energy infrastructure such as wind turbines and solar panels. Vidal, Goffé, & Arndt (2013) found that while renewable energy is effective in reducing carbon emissions, “wind turbines and photovoltaic panels also require enormous amounts of common metals such as iron, copper and aluminum, as well as sand and industrial minerals to make concrete and glass, and hydrocarbon derivatives to create resins and plastics” (p.895). They recommend increasing recycling to reduce the need for extraction, research to find substitute metals, and care in the design of technology to reduce the need for these materials (Vidal, Goffé, & Arndt, 2013). Solar panels generate electricity from silicon, but silicon is the second most common element in the crust of the Earth (Encyclopedia of Earth, 2008). Bradshaw, Reuter, & Hamacher (2015) note that the generation, storage, and transmission of sustainable energy forms will require large quantities of rare elements. Bradshaw, Reuter, & Hamacher (2015) assume a doubling of global energy demand by 2050 and a 60% renewable penetration rate and conclude that only a small fraction of the rare earth element reserves will be needed or 1-2 Mt (megatons) of the 140 Mt thought to be available for mining (Bradshaw, Reuter, & Hamacher, 2015, p. 10). They do not factor in the replacement of internal combustion vehicles with electric vehicles, but even a doubling of the demand would not come close to straining total reserves. Some rare earth elements are rarer than others though and a look at individual elements shows that consumption of these elements at the levels described here would not lead to their total exhaustion (Bradshaw, Reuter, & Hamacher, 2015). Some rare earth elements are used in the production of thin film and crystalline solar panels, lithium ion batteries, light emitting diode (LED) bulbs, semiconductors, touch panels, nuclear reactors, and magnets in wind and hydroelectric turbines.

Mai, et al. (2012b) also do not anticipate of running out of materials needed for a renewable energy transition. They recognize that the challenges in the renewable energy industry could extend to many aspects of the industries' supply chain, including raw materials availability, project development and siting, equipment manufacturing, and labor needs but go on to say that they did not identify any insurmountable long-term constraints to materials supply, manufacturing capacity, or labor availability for any renewable energy technology.

Alternative power plants that burn municipal waste, sawmill waste, paper mill waste, and other biomass also have supply chain limitations. For example, Sweden constructed waste-to-energy plants that supply heat and electricity to homes, but have recently faced a shortage in the waste available to burn due to increased recycling efforts (PRI, 2012). They have turned to importing trash from other European cities to supply their waste-to-energy power plants (PRI, 2012). There are also concerns that biomass plants that were intended to burn waste wood will turn to harvesting and burning trees if faced with a shortage (PFPI, 2011).

Siting issues are a concern with many sources of renewable energy, with respect to impacts on wildlife, health impacts on humans, and aesthetics. Wind can kill birds (Bailey et al. 2012), solar panels and wind turbines are considered unsightly by some (Freeman & Parks, 2016), hydroelectric dams can harm fish and are responsible for blocking sediment (Winemiller, et al., 2016), and noise from wind turbines has been shown to adversely affect human health (Pedersen & Waye, 2007; Shepherd, et al. 2011). While there are environmental impacts from renewable energy facilities, there are also similar siting issues with respect to fossil fuel plants in terms of water, air, and soil pollution, adverse impacts on wildlife, health impacts on humans, and aesthetics.

Capacity Factor

Various sources of electricity have their own capacity value. Capacity factor is the proportion of the nameplate capacity that a generator can actually produce. For instance, a 600MW coal plant may be able to produce 3.7 terra watt hours (TWh) of electricity in a year if it runs 24 hours a day 365 days in a year (600 MW x 24 x 365 x

70% = 3,679,200 MWh) using a capacity factor of 70% due to normal losses from maintenance. In comparison, a 600MW solar plant might only produce 1TWh (600 MW x 24 x 365 x 20% = 1,051,200 MWh) of electricity in a year because of the time the sun does not shine or the time that clouds reduce production resulting in a capacity factor of 20%. Because of this disparity in capacity factor, a much larger nameplate capacity of assets are necessary to generate the electricity needed. For instance, a utility may own seven coal and gas power plants with an average nameplate capacity of 600MW and a total nameplate capacity of 4.2 GW. With a capacity factor of 70% they could conceivable produce 25.7 TWh of electricity. In order to produce that much electricity from solar arrays with a 20% capacity factor 20.2 GW of solar nameplate capacity would be needed. Because of this, it is important when comparing electricity generation options to not limit the calculations to capacity, but also examine kWh generation.

Local Sources

It is important economically and socially to transition to new sources of energy from local resources because many cities already produce a large percentage of their own energy. Cities in coal states are heavily dependent upon coal for electricity because proximity lowers transportation costs and because local sources provide jobs and keep profits local. Similarly, cities near the Gulf of Mexico get a large percentage of their electricity from natural gas. Convincing a city to move to a source of energy that would require most or all of that energy to be purchased from other locations would not be politically popular or economically beneficial. Transmission losses are also minimized when electricity is produced locally. Keeping jobs in the area is important to the economic vitality of the region during the transition to renewable sources. From a national perspective, moving away from imported oil would enhance national security (Su, Rahimi-Eichi, Zeng, & Chow, 2012), benefit foreign policy (Deutch, & Moniz, 2010) and there are economic benefits when energy imports are reduced.

Louisville, Kentucky

Louisville, Kentucky was chosen for this study because it lies within a coal state and thus provides a robust test of viability. Coal states have traditionally derived the vast majority of their energy from within the state thus making it difficult to transition to renewable sources. Kentucky has a long history with fossil fuel extraction. Kentucky's first oil well was struck in 1818 and its first coal mine dates to 1790 (Kentucky Foundation, n.d.; Kentucky Energy and Environment Cabinet, 2014). As recently as 2013, coal mining directly contributed billions of dollars to the economy of Kentucky (Kentucky Energy and Environment Cabinet, 2014) and the state ranks third in the nation in coal production.

The city of Louisville, in Jefferson County, Kentucky is the largest city in the state and generates more than 95% of its electricity from fossil fuels, principally coal (EIA, 2015b). In order to make progress on reducing its environmental impact, the city government has made some commitments to carbon reduction. The Mayor of Louisville made a commitment to reducing the city's carbon emissions to 7% below 1990 levels by 2012 by signing the U.S. Conference of Mayors' Climate Protection Agreement (2005), and the city's Sustain Louisville (2013) plan calls for 20% reductions in transportation-related emissions by 2020 and a 25% reduction in per capita energy use by 2025. It is not known whether the city met the 7% reduction target since those commitments were not evaluated, but it is unlikely seeing that the state-wide emissions increased by 15% during the period 1990 to 2012 (EPA, 2016). Although the Sustain Louisville plan has these goals, it does not delineate the specific steps that will be taken to accomplish them.

While Louisville is a Silver-level Bicycle Friendly Community as determined by the League of American Bicyclists (2015), it is also a very car-dependent city as shown by the census data. In 2005, Louisville, the 30th largest U. S. city by population, was ranked 61st in Vehicle Miles Traveled (VMT) according to the Brookings Institute (2005). The American Council for an Energy-Efficient Economy ranked the state of Kentucky tied for last place in its 2013 State Energy Efficiency Scorecard for transportation policies (Downs, at al.,. 2103). This scorecard looks at policies in place to address greenhouse gas emissions, integration of land use and transportation, VMT targets, transit funding, complete streets legislation and high efficiency vehicle incentives (Downs, at al.,. 2103).

The University of Kentucky College of Agriculture prepared a white paper delineating the resources that are available to help the state reduce its energy consumption and increase its renewable energy production 25% by 2025 (Colliver, 2008). They reported high rates of consumption by Kentucky consumers, noting that the average energy consumption per person is among the highest in the country (Colliver, 2008). According to the EIA (2015d) Kentucky is ranked 11th in total per-capita energy consumption at 414 million BTUs per person, 45th in electricity costs at 8 cents per kWh, and 15th in total energy expenditures at $5,097 per person per year. The low rates and high total costs indicate that Kentucky residents and businesses are wasting a lot of their energy.

Table 1. LG&E power plants and production (Louisville Gas and Electric Company, 2014; Kentucky Public Service Commission, 2013a).

Plant	Type	2013 Net Generation, Exclusive of Plant Use MWh	Capacity MW	Percent of total production
Cane Run (1954)	Coal	2,556,296	645	16.5%
Mill Creek (1972)	Coal	8,286,913	1,482	53.5%
Falls of the Ohio (1928)	Hydro	193,332	80	1.2%
Paddy's Run (1968)	Gas	15,310	214	0.1%
Trimble County (1990)	Coal	4,268,436	489	27.6%
Cane Run (1968)	Gas	180	14	0.0%
Zorn Avenue (1969)	Gas	203	14	0.0%
E. W. Brown (1999)	Gas	37,198	184	0.2%
Trimble County (2002)	Gas	122,996	350	0.8%
Total		15,480,864	3,472	100.0%

Louisville's electricity is generated by Louisville Gas and Electric Company (LG&E), a subsidiary of the publically traded PPL Corporation. The utility provides electricity to 400,000 customers in Louisville and 16 surrounding counties (Louisville Gas and Electric Company, 2015). The company operates nine generating plants (Table 1). Most of the electricity produced in 2013 (97.6%) was from the three coal-fired power plants, while only a small portion was from the only hydroelectric plant (1.2%) and the remaining 1.1% was generated with natural gas. In an attempt to reduce air pollution (including carbon dioxide), the company constructed a combined-cycle natural gas plant at the Cane

Run site in 2015 and closed its coal-burning plant there (Bruggers, 2015c). Construction of this plant was a substantial investment in a non-renewable asset with a useful life of 55 years that will continue to emit greenhouse gases (Short, et al., 2011). With 98.8% of its electricity generated by non-renewable sources, huge changes will have to take place to achieve a 100%-renewable portfolio. The total installed capacity for electricity generation by solar energy in the city is not known, but is thought to be just less than 1 MW from small arrays on approximately 200 customer's roofs (Bruggers, 2015a). LG&E does have plans to construct a 10 MW solar array at its E. W. Brown site in 2016. There is no known wind generation in Metro Louisville.

The Transit Authority of River City (TARC) added 10 all-electric Zero Buses to their fleet in 2015 to service the downtown area with two charging stations (TARC, 2016). The city does have a Tesla Supercharger station at Sullivan University in the Highlands neighborhood and another charging station at The Green Building in the NuLu District (Courier-Journal, 2016). The University of Louisville has eight charging stations on their Belknap Campus, six, level 2 charging stations in their Floyd Street garage available to the public and two level 1 chargers at the Service Complex at Brook and Warnock Streets to power the University's two electric vehicles (Kentucky Clean Fuels Coalition, n.d.). Louisville International Airport has two level 2 chargers available to the public (Louisville Regional Airport Authority, n.d.). There are many other charging stations around the city and more planned for the near future.

Research Questions and Hypotheses

This research will evaluate three major questions and three hypotheses:

1) What financial costs and land use changes are needed for Louisville to convert its electricity to all-renewable energy sources while also meeting the added demand of an all-electric fleet? For this transition to be feasible, the financial costs would have to be manageable. While some citizens might be willing or able to pay more for cleaner air and a more stable climate, many people are not willing or able to pay a lot more for these. Land use is another cost that needs to be assessed. People may be willing to accept solar panels on buildings and parking lots, for instance, but not on parks and in front yards. In order to balance the need for mitigating climate change and the need to preserve green space or neighborhood appearances, communities will need to make difficult decisions about how to accommodate these conflicting principles. It is hypothesized that to produce all of the electricity needed to meet Louisville's current demand, as well as powering all of the city's vehicles, an enormous amount of land and money will be required.

2) How much energy demand reduction from conservation and efficiency is possible to help make this conversion more affordable and to avoid having to buy significant amounts of electricity from other locations? Reducing demand for electricity through conservation and efficiency may offset the cost of electricity due to rate increases. It is hypothesized that conservation and efficiency can help to make the transition more affordable in terms of land use and financial constraints.

2) How much renewable energy from sources other than solar is available to help make this conversion more affordable and to avoid having to buy significant amounts of electricity from other locations? It is hypothesized that ample local renewable energy

sources other than solar are available to help Louisville make the transition more affordable in terms of land use and financial constraints.

Chapter II

Methods

The research methods used to determine the scope of converting the electricity grid to renewable sources and replacing all vehicles with electric vehicles, and measuring the amount of renewable energy sources available to Louisville involved the gathering of information and data from the local sources and applying formulas to determine the amount of solar generating assets needed, the technical hurdles needing to be addressed, and the amount of non-solar renewable resources available. Local transportation data included the number of vehicles owned by residents, number of vehicles that commute to the city on a regular basis, the average number of vehicle miles traveled (VMT) per person, and the number of people that use alternative forms of transportation. The calculations performed in this study include the number of internal combustion vehicles needing to be replaced with electric vehicles, the amount of renewable electricity needing to be generated to power those vehicles, the amount, space, and cost of solar panels to generate that electricity, the amount of other renewable energy available to the city, and the amount of electricity able to be saved through conservation and efficiency measures.

Transportation

In order to determine the number of internal combustion vehicles needing to be replaced with electric vehicles, three sources were combined: passenger vehicles residing in the city, passenger vehicles commuting into the city, and commercial vehicles. U. S. Census Bureau (n.d.c.) data from 2013 was used to determine the number of passenger vehicles owned by Louisville residents, and the 2015 estimate was projected by using the average percentage increase over the past four years. The number of vehicles commuting to the city from the top 38 of 351 counties in Kentucky and surrounding states was obtained from the U. S. Census Bureau (n.d.d). Since 351 counties reported commuters to the city and many of those were not within reasonable driving distance (e.g. many states away), the top 38 counties were selected. These commuter numbers were adjusted to account for non-driving passengers in the vehicles. The U.S. Census Bureau (n.d.d) data was given in a range of quantities. The high and low of the range were averaged to determine the number of non-driving passengers for reducing the number of vehicle commuters to obtain the total number of vehicles. Using the number of 2014 commercial vehicles per Charla Masters (personal communication, September 22, 2015) of the Kentucky Department of Motor Vehicles, the 2015 quantities were projected using the average percentage increase over the past five years.

Increase in Demand from Electric Vehicles

To calculate the electricity needed to power the vehicles housed in, or commuting to the city under a 100% electric vehicle scenario, the average annual vehicle miles traveled was obtained from the Louisville Metro Air Pollution Control District (personal communication, Keith Talley, 2014). The weighted average kWh per mile was calculated based on the electric vehicles sold in the U. S. between December 2012 and April 2015 per the U. S. Department of Energy (2014). The miles per gallon equivalent (MPGe) and kWh per 100 miles were obtained from the vehicle specifications from their respective manufacturer's website. To calculate the weighted average, the sales were multiplied by the kWh per mile for each make and model and the total of this was divided by the total sales.

Conversion of the Existing Grid to Solar

The installed capacity for sufficient solar photovoltaic panels was calculated using the 2014 production numbers for LG&E per the Kentucky Public Service Commission (2013b) and an assumed capacity factor of 10%. This 10% is considered conservative compared to the 13% capacity factor used for Louisville, Kentucky by the National Renewable Energy Lab PVWatts Calculator. The projected cost of $1.50 per installed watt was provided by Bronski, et al. (n.d.) and the number of panels and surface area were calculated using a 310 watt panel and the dimensions for a Renesola polycrystalline panel from Websolar.com (n.d.) as a typical panel being used today. Surface area calculations were performed in order to determine the amount of space needed for this amount of solar photovoltaic electricity production. The formula used was as follows: capacity calculated in MW x 10 % capacity factor x 8765.81 hours in year = production in MWh. The number of panels was calculated by dividing the capacity by wattage of a single panel (310 watts). The surface area was calculated my multiplying the number of panels by the square yardage of a single panel (2.32 square yards) and then converting to acres.

Population and Growth

Population growth was based on Granade, et al. (2009) who expect a 0.7% average increase in electricity demand annually until 2050 and ProximityOne (n.d.) that projects population growth for Jefferson County of 0.62% annually through 2060. It was assumed that the vehicle numbers increased with population growth.

Conservation and Energy Efficiency

A calculation of weighted average energy efficiency savings spreads the gross production of MWh electricity by LG&E of (Kentucky Public Service Commission, 2013a) into residential, commercial, industrial, and governmental sectors based on their percentage of total sales (Kentucky Public Service Commission, 2013b). The amount of electricity produced for each sector is multiplied by the average percent savings from energy efficiency as calculated by Grenade (2009) to determine the gross energy savings by sector in MWh. The total gross savings of the four sectors divided by the total production resulted in the weighted average savings from energy efficiency. The efficiency savings are used to calculate the amount of energy reduced, and the corresponding reduction in solar investment that can be eliminated. Assuming 15.8% reductions in transportation by automobile (0.45% per year based on Boulder, CO) (Henao, at al., 2014), then the number of vehicles needing to be replaced with electric vehicles was reduced by that percent as was the amount of electricity needing to be produce and corresponding reduction in solar panels needed.

Other Renewable Energy Sources

The total electricity available for Louisville from renewable sources other than solar was calculated in two ways. The first is for bioenergy and the second is for wind and hydroelectricity.

Bioenergy

To determine the amount of renewable energy that is available for Louisville, data for potential biomass energy sources came from Milbrandt (2005), NREL (2015a), U. S. Department of Agriculture (2015), Robert Bates, MSD Biosolids Administrator (personnel communication, July 30, 2015), and Marie Burnett (personal communication, June 5, 2015). The biomass sources were limited to only Jefferson County and the contiguous counties that surround it. In the interest of conservatism, the lower limit available energy was used for each of the source estimates when a range was given. Conversion rates for changing dry tones and standard cubic feet per year to MWh of electricity for the various types of biomass were obtained from Augustine, et al. (2012), Robert Bates, MSD Biosolids Administrator (personnel communication, July 30, 2015), Marie Burnett (personal communication, June 5, 2015) and the U. S. Department of Energy Oak Ridge National Laboratory . The following formula was used: amount of biomass in tons or standard cubic feet per year x rate of conversion to energy = amount of energy in MWh.

Wind and Hydroelectricity

Since Louisville comprises 17% of the state's total population, then 17% of potential state-wide wind and hydroelectricity generation were deemed available for use by the city in this model. The sources used for the amount of energy produced by wind and hydro were from studies conducted by Kao, et al. (2014) and Bailey, et al. (2012). Wind energy production was calculated using a conservative 10% capacity factor and the following formula: state-wide capacity (MW) x hours in a year x 10% capacity factor x 17% = electricity production available for Louisville (MWh). The 10% capacity factor was obtained from Bailey, et al. (2012). Hydroelectricity production was calculated by simply multiplying the state-wide electricity production estimate from Kao, et al. (2014) by 17%.

Land Usage for Solar Panels

A search for suitable sites for solar arrays resulted in three categories of installations: rooftop arrays, urban land-based arrays, and rural solar arrays. The rooftop arrays and urban land-based arrays were identified and the sized estimated. The rural solar array capacity was calculated using the balance of the total capacity needed and compared to other calculations for reasonableness. To determine the total capacity for solar electricity generation in Louisville, estimates were made of the available space on rooftops, select parking lots, and other non-arable lands in the city. Wiese, Libby, Long, & Ryan (2010) estimated that 26.5% of the rooftop space in Austin, Texas was suitable for solar after factoring out roofs that were structurally unsound, improperly oriented, and shaded. Melius, Margolis, & Ong (2013) reviewed 35 studies of rooftop solar potential for cities and found that the percentage of suitable roof space ranged from 1.31% to 65%. The Austin, Texas percentage was used as a conservative estimate compared to the 1.31% to 65% range. Measurements were taken of select parking lots and other non-arable land sites using the Google Earth measurement tool. ArcGIS software and building data provided by the Louisville/Jefferson County Information Consortium was used to obtain the total roof space in the city.

Storage Capacity of Electric Vehicles

Using the projected number of electric vehicles from the Population and Vehicle Growth section above and after factoring in reductions in vehicles as delineated in the Conservation and Energy Efficiency Improvements section, the number of vehicles was multiplied by the weighted average battery pack capacity and an assumed 20% charging loss factor to determine the total storage capacity of Louisville's electric vehicle fleet. The weighted average battery back capacity was determine by multiplying the battery capacity of each of the electric vehicles sold in the U. S. between December 2012 and April 2015 per the U. S. Department of Energy (2014). The battery capacities were obtained from the vehicle specifications from their respective manufacturer's website. To calculate the weighted average, the sales were multiplied by the battery capacity for each make and model and the total of these is divided by the total sales.

Chapter III

Results

Transportation

According to calculations based on data from the U. S. Census Bureau (n.d.) there are about 670,000 vehicles registered in Louisville including commercial vehicles and vehicles driven by commuters from outside the city. There are about 98,000 commuters to Louisville from 39 counties in Indiana, Ohio, and Kentucky, which includes only those counties where 100 or more vehicles commute to Jefferson County (U. S. Census Bureau, n.d.). Additionally, records show that about 12,700 people commute to work using Transit Authority of River City (TARC) buses, 1,200 bicycle to work, 6,400 walk to work, and 9,100 work from home (Census Transportation Planning Products, n.d.; U. S. Census Bureau, n.d.).

Downs, et al. (2013) estimate that there were 2.7 electric cars for every 100,000 people in Kentucky in 2011. Even with 760,000 people in Louisville in 2011 and assuming that the number of electric cars grew by 20% annually since then, there would still be less than 100 EVs in the city by 2016. It is probable that the EV ownership percentage is higher in the city than rural parts of the state so this estimate could be low.

Increase in Demand from Electric Vehicles

Table 2. Electric vehicle weighted average kWh per mile.

Make Model	MPGe	kWh/100 m	kWh/mile	Sales 12/10- 4/15	kWh/mile x sales
Nissan Leaf	99	34	0.34	77,942	26,500
Tesla Model S	94	36	0.36	44,521	16,028
BMW i3 REx	117	29	0.29	9,179	2,662
Ford Focus EV	105	32	0.32	4,879	1,561
Smart ED (3G)	107	32	0.32	4,014	1,284
Chevy Spark EV	119	28	0.28	2,981	835
Fiat 500E	116	29	0.29	2,613	758
Toyota RAV4 EV	76	44	0.44	2,398	1,055
Mitsubishi i-MiEV	112	32	0.32	1,920	614
Cadillac ELR	82	41	0.41	1,731	710
Mercedes B-Class EV	84	29	0.29	1,426	414
Volkswagon e-Golf	116	29	0.29	1,172	340
Honda Fit EV	118	29	0.29	1,070	310
BMW i8	76	43	0.43	1,034	445
BMW ActiveE	102	33	0.33	965	318
Kia Soul EV	105	32	0.32	503	161
Smart ED (2G)	87	39	0.39	312	122
Totals				158,660	54,117
Weighted average kWh/mile					0.341

Projections using U. S. Census (n.d.) data indicate there are approximately 396,278 passenger vehicles and 178,408 commercial vehicles in Louisville. Calculations using Census Information Planning Products (n.d.) data indicate there approximately 95,771 (with margin of error of 2,117) passenger vehicles that regularly drive into

Louisville bringing workers. This many vehicles (approx. 670,000) would require 3 GWh of electricity per year to operate, assuming a weighted average of .341 kWh of electricity per mile (Table 2) and an average of 12,734 miles driven per year (personal communication, Keith Talley, Director, Louisville Metro Air Pollution Control District, 2014). In order to power these vehicles using exclusively solar-generated electricity, 2.3 million solar panels would be necessary at a cost of about $ 5 billion (using $1.50 per watt installed and a 10% capacity factor; Bronski, et al., n.d.) (Table 3). That amounts to 3,381 MW of new generating capacity that must be added to the grid. LG&E currently has 3,472 MW of generating capacity.

Conversion of the Existing Grid to Solar

In order to achieve an all-solar scenario, it is assumed that LG&E would start constructing solar PV arrays, smaller at first, then larger as time goes on. It is further assumed that coal and natural gas plants would reduce their production until totally phased out by 2050. Based on these assumptions, within ten years of continual conversion, over 50% of the energy on the grid could be derived from solar, and by 2050 the utility could reach 100% solar. This would require 17,440 MW of installed capacity (Table 3), enough to power all of the homes, businesses, and industry, exclusive of anticipated changes in electric vehicle use. The cost for these arrays, at $1.50 per installed watt (Bronski, et al., n.d.), would be $26.2 billion and require 42.1 square miles of space, or 10.6 % of the area of the city of Louisville.

Population and Growth

The requirements for converting the existing electricity demand to solar energy were calculated (Table 3) along with the added demand if all 670,000 existing internal combustion vehicles were replaced with electric vehicles (lines a. – c.). Since the number of vehicles in the city will likely grow as the population grows, and the demand for electricity is expected to grow as well (EIA, 2015d). Granade, et al. (2009) expect a 0.7% average increase in electricity demand annually until 2050. ProximityOne (n.d.) projects population growth for Jefferson County of 0.62% annually through 2060. Total projected demand in 2050 for electricity will be over 18.9 TWh (line e.). The solar panels need to supply the total electricity for Louisville, inclusive of conversion to an all-electric fleet and anticipated growth in population, would take up 52 square miles of space, or 13 % of the surface area of the city.

Table 3. Solar electricity demand based on current levels of usage.

Conversion	Panels needed	Cost (at $1.50 per installed watt)	Name plate capacity needed	Generating capacity needed
a. Electricity generation to 100% renewable	56.2 million	$26.2 billion	17,440 MW	15.3 TWh
b. All 670,000 vehicles to electric	2.3 million	$5.0 billion	3,381 MW	.6 TWh
c. Current totals	58.5 million	$31.2 billion	20,821 MW	15.9 TWh
d. Increase in demand and increase in vehicles	10.9 million	$1.1 billion	706 MW	3.0 TWh
e. Total needed	69.4 million	$32.3 billion	21,527 MW	18.9 TWh

Conservation and Energy Efficiency

Calculations of potential energy efficiency and conservation savings from the residential, commercial, industrial, and governmental sectors of electricity consumers resulted in a weighted average 26.5 % decrease in electricity over the next 35 years (Table 4). Additionally, with an assumption of 15.8% reductions in transportation (0.45% per year based on Boulder, CO) (Henao, at al., 2014), the number of solar panels could be reduced by 17.8 million to 51.6 million by 2050.

Table 4. Calculation of weighted average energy efficiency savings, Louisville, Kentucky.

Sector	% of total sales	Gross production (MWh) (Kentucky Public Service Commission, 2013a)	Savings % (Grenade, 2009)	Gross savings (MWh)
Residential	35.6%	5,510,542	25.8%	1,422,409
Commercial	31.5%	4,876,644	31.0%	1,511,815
Industrial	23.1%	3,573,118	17.7%	631,304
Governmental	9.7%	1,496,739	35.6%	532,985
Lighting	0.2%	23,821	A	4,098,513
		15,480,864	Gross production	
less lighting		(23,821)		
B		15,457,043	Gross production less lighting	
Weighted average savings			26.5%	(A/B)

The amount of electricity needed to convert all of the current electricity generation to 100% solar, but also reducing the electricity needed for EV's by 15.8% and overall consumption by 26.5% to account for increases in efficiency was determined (Table 5). Factoring in conservation and efficiency, the transition of the existing electricity production to solar energy with enough electricity to power electric cars would cost $24 billion and require 51.6 million panels that would require 38.6 square miles of space, or 9.7% of the area of the city of Louisville.

Table 5. Solar electricity demand after employing conservation or efficiency in buildings and the transportation.

Conversion	Panels needed	Cost (at $1.50 per installed watt)	Name plate capacity needed	Generating capacity needed
a. Electricity generation to 100% renewable and all vehicles to electric	69.4 million	$32.3 billion	21,527 MW	18.9 TWh
b. Decrease in demand due to conservation in buildings and vehicles	17.9 million	8.3 billion	5,540 MW	4.9 TWh
c. Total in 2050	51.6 million	$24.0 billion	15,987 MW	14.0 TWh

Other Renewable Energy Sources

In total, there is at least 1,224.5 GWh of non-solar renewable energy potential that can provide electricity to Louisville (Table 6). By including these non-solar sources of renewable energy, the cost of solar would be reduced by $2.1 billion and 4.5 million panels and result in an adjusted total cost of $21.9 billion and require 47.1 million panels that would require 35.3 square miles of space, or 8.8% of the area of the city of Louisville (Table 7).

Table 6. Electricity generation potential from renewable energy sources other than solar.

Source	Location	Generating capacity available
Biomass		
Dedicated crops, trees	Farms in surrounding counties	29.7 GWh
Dedicated crops, grass	Farms in surrounding counties	19.8 GWh
Urban tree waste	City at large	55.0 GWh
Manure	Farms in surrounding counties	97.8 GWh
Sewage	MSD plants	57.4 GWh
Landfill gas	Outer Loop Landfill	8.7 GWh
Industrial, commercial, and institutional food waste	City at large	7.1 GWh
Agricultural residues	Farms in surrounding counties	175.5 GWh
Forest residues	Forests in surrounding counties	51.9 GWh
Secondary mill residues	Industry in surrounding counties	47.3 GWh
Total biomass		550.2 GWh
Hydroelectricity	Other in-state locations	561.1 GWh
Wind	Other in-state locations	113.2 GWh
Total		1,224.5 GWh

Table 7. Solar electricity demand after employing other renewable energy sources.

Conversion	Panels needed	Cost (at $1.50 per installed watt)	Name plate capacity needed	Generating capacity needed
a. Electricity generation to 100% renewable and all vehicles to electric	69.4 million	$32.3 billion	21,527 MW	18.8 TWh
b. Decrease in demand due to conservation in buildings and vehicles	17.9 million	$ 8.3 billion	5,540 MW	4.8 TWh
c. Total	51.6 million	$24.0 billion	15,987 MW	14.0 TWh
d. Electricity renewable sources other than solar	4.5 million	$ 2.1 billion	1,398 MW	1.2 TWh
e. Total in 2050	47.1 million	$ 21.9 billion	14,589 MW	12.8 TWh

Land Usage for Solar Panels

Suitable sites for solar arrays included three categories of installations: rooftop arrays, urban land-based arrays, and rural solar arrays.

Louisville has over 190 million square feet of rooftop space on buildings. Using the Austin, Texas percentage as a conservative estimate, 26.5% of roof space, or 50.3 million square feet in Louisville was deemed suitable. This is enough space for about 2.4 million panels that could produce about 655.1 GWh of electricity.

Thirteen large parking lots were identified using Google Earth as possible locations for carport solar arrays. These 13 lots comprise 15 million square feet of space (Table 8), enough for 718,000 solar panels that could produce 195.2 GWh of electricity per year.

Table 8. Largest parking lots in Louisville, Kentucky.

Facility	Square feet	No. solar panels
General Electric	1,729,933	82,851
Kentucky Fair and Exposition Center	1,587,236	76,017
Papa John's Stadium, University of Louisville	1,481,029	70,931
Ford Louisville Assembly Plant	1,366,134	65,428
Jefferson Mall	1,345,242	64,427
Ford Kentucky Assembly Plant (KTP)	1,328,022	63,603
Oxmoor Mall	1,313,248	62,895
Southeast Christian Church	1,198,553	57,402
Mall St. Matthews	1,141,104	54,651
Churchill Downs	986,382	47,241
United Parcel Service	940,025	45,020
Louisville International Airport	309,872	14,841
Louisville Zoo	271,978	13,026
Totals	14,998,758	718,331

The city also has a number of federal rights of way that could house solar arrays including, the 38 interchanges along I-264, I-265, I-64, I-65, and I-71 and also the rest area on I-71 near Harrods Creek. There is also the possibility that panels could parallel the interstates as were considered in 2015, but not built, along I-265 near Dixie Highway (Figure 7) as part of the Dixie Highway Improvement Project (Pohlman, 2013). There is land adjacent to the Louisville Gas & Electric Company's combustion plants that could be used for utility-scale solar production similar to the array that is being installed at their E. W. Brown plant in Mercer County. This could include the LG&E power plant sites of Cane Run, Mill Creek, Patty's Run, Zorn Avenue, and Trimble County. These areas constitute another 2.3 million square feet of space or 110 thousand solar panels. This comes to a grand total of rooftop and urban land-based arrays of 67.6 million square feet, enough to house over 3.2 million solar panels that could produce about 880 GWh of electricity.

Fig. 7. Artist depiction of solar array along highway as proposed for I-264 near the Dixie highway interchange (Pohlman, 2013).

In order to house 47.1 million solar panels (Table 7), subtracting the 3.2 million panels provided by urban sites results in 43.8 million panels that would have to be installed outside the city on suitable sites or 93.1% of the total. This would require 21,020 acres.

Table 9. Electric vehicles weighted average battery capacity.

Make Model	Battery capacity (kWh)	Sales 12/10- 4/15	kWh x sales
Nissan Leaf	24.0	77,942	1,870,608
Tesla Model S	70.0	44,521	3,116,470
BMW i3 REx	18.8	9,179	172,565
Ford Focus EV	23.0	4,879	112,217
Smart ED (3G)	17.6	4,014	70,646
Chevy Spark EV	19.0	2,981	56,639
Fiat 500E	24.0	2,613	62,712
Toyota RAV4 EV	41.8	2,398	100,236
Mitsubishi i-MiEV	16.0	1,920	30,720
Cadillac ELR	17.1	1,731	29,600
Mercedes B-Class EV	36.0	1,426	51,336
Volkswagon e-Golf	24.0	1,172	28,128
Honda Fit EV	20.0	1,070	21,400
BMW i8	7.1	1,034	7,341
BMW ActiveE	32.0	965	30,880
Kia Soul EV	27.0	503	13,581
Smart ED (2G)	16.5	312	5,148
Totals		158,660	5,780,229
Weighted average kWh			36.432

Based on the projected population and corresponding vehicle growth as reported in the Population and Vehicle Growth section above and after reductions in vehicles as delineated in the Conservation and Energy Efficiency Improvements section, the total vehicles by 2050 will number 779,940, with 668,646 being housed within the city and 111,293 owned by commuters from outside the city. Louisville's 2050 projected 668,646 vehicles could store 19.5 GWh or enough electricity to power 21,392 homes for one month. The 19.5 GWh total storage capacity of Louisville's projected 668,646 vehicles amounts to 0.1% of the total projected amount of generating capacity needed for the city.

Chapter IV

Discussion

As the results indicate, replacing all of Louisville's vehicles with electric vehicles and converting the grid to 100%-renewable sources is a monumental task that will cost nearly $22 billion and require 35 square miles of solar panels. Major changes will need to take place in many sectors of the city. Conservation and efficiency with the transportation and electricity consumption sectors will be required. Major changes will be needed in electricity generation at homes and businesses and by Louisville, Gas and Electric Company. Converting from fossil fuel electricity generation to renewable energy generation can create new opportunities but also difficulties for the community and for LG&E. The utility's employees are experts in electricity generation from fossil fuels, but have little experience in renewable energy generation other than hydroelectricity. They will have to learn much about renewable energy generation like they are starting to do with their E. W. Brown 10 MW solar array. In researching a conversion of this magnitude a number of potential problems were discovered and are discussed here along with recommendations for addressing the issues.

Increase in Demand from Electric Vehicles

Replacing all internal combustion vehicles in Louisville with electric motor vehicles will increase the demand for electricity by 18.9 TWh. Such an increase in demand would not only require additional generating capacity, but LG&E will also need to undertake transmission and distribution infrastructure upgrades (U.S. Department of Energy, 2009). Transmission and distribution infrastructure has limits to the amount of electricity that can be transmitted and aging infrastructure limits that even more (U.S. Department of Energy, 2009). The Department of Energy (2009) notes that congestion occurs on the grid when flows of electricity across a line or piece of equipment are restricted below desired levels, and this is usually due to the conducting limitations of that equipment.

Solar Conversion Grid to Solar

The results indicate that the replacement of internal combustion vehicles with electric vehicles and the conversion of the grid to renewable energy will require the installation of 14,589 MW of solar capacity, or about 47.1 million panels even after employing conservation and efficiency and non-solar renewable energy. The results further indicate that only 6.9% of the solar can be constructed within the city while the remaining 93.1% will need to come from rural utility-scale solar arrays. These results are in line with Jacobson, et al. (2014a) who indicated that 5.3% of Kentucky's electricity (1,760 MW) could come from rooftop solar PV and 85% (26,800 MW) could come from utility-scale solar PV by 2050. However, the Department of Energy (2012a) estimates that Kentucky only has enough solar radiance to accommodate 5,900 MW of solar photovoltaic electricity capacity by 2050. Lopez, et al. (2012), on the other hand, estimated that Kentucky can technically produce 12.3 TWh of electricity annually from rooftop solar PV, 1,824 TWh from rural utility-scale PV, and 26.5 TWh from urban utility-scale PV for a total of 1,862.8 TWh of electricity.

Of the over 190 million square feet of rooftop space on Louisville's buildings, those roofs that face south or that are flat would have greater potential for solar generation, while those that are north facing would have the least (Chaves & Bahill, 2010). Even roofs that face east or west would be able to produce solar energy, just not as much. Lazar (2014) recommends orienting solar panels to the west instead of the traditional direction of south to increase evening production at the expense of morning production and help to meet the evening peak in demand. Roofs that are shaded by trees or other buildings should not be used due to their reduced production capacity and thus longer investment payback. Melius, Margolis, & Ong (2013) reviewed 35 studies of rooftop solar potential for cities and found that the percentage of suitable roof space ranged from 1.31% to 65%. Wiese, Libby, Long, & Ryan (2010) estimated that 26.5% of the rooftop space in Austin, Texas was suitable for solar after factoring out roofs that were structurally unsound, improperly oriented, and shaded, this was the percentage used in this study. Additional research will be needed to obtain a more accurate estimate.

There are other consequences to having such a large dependence upon solar. The increased prevalence of distributed solar on rooftops and parking lots throughout the city will actually reduce congestion on the grid because the sources of the electricity generated will be closer to those consuming it (U.S. Department of Energy, 2009). At the same time, there are concerns about the effect of energy that flows in from solar that is distributed across the grid. Voltage can vary significantly and suddenly when large amounts of solar energy are added to the grid (Trabish, 2014). The flow of electricity backwards and forwards on a grid designed to go in one direction can potentially damage distribution and transmission system equipment (Trabish, 2014). Upgrades to Louisville's grid infrastructure may be needed as solar penetration levels increase.

Variability of sunlight is also a concern when using large amounts of solar. For LG&E to address the variability issues, a number of strategies could be implemented. Mai, et al. (2012a) ran models for a scenario that includes 90% renewable energy and conclude that "the variability and uncertainty associated with these high levels of wind and PV penetration were found to be manageable" (p 34). Mai, et al. list six strategies that can help LG&E to manage the variability issue. The first is "the application of adequate flexible generation capacity" (p 34) from bioenergy sources that can be stored and burned when needed to convert to electricity. As indicated in Chapter III, Louisville has the resources to generate 550.2 GWh of electricity from bioenergy sources. The second strategy proposed by Mai, et al. (2012a) is "the use of grid storage" (p 34) will likely play a larger role than bioenergy and can be dispatched within a moment's notice. Storage options for Louisville are discussed in detail below. Thirdly, demand-side technologies reduce the amount of overall electricity that is needed. Demand-side technologies include smart grid, demand response, time-of-day pricing, and direct load control and are also discussed in more detail below. The fourth strategy involves expansion of the transmission infrastructure which allows electricity generated in one region of the country to be easily transmitted in greater quantities to other regions of the country when one region is lacking another may have excess. Their final strategy for mitigating the impacts of variability is greater flexibility in dispatching for conventional power plants, including significant daily ramping of fossil generators. This strategy can be used in the transition but this will not be needed once the conversion is achieved because it involves the use of fossil fuels.

Efficiency and Conservation

In order to achieve a conversion of the electricity grid to 100% renewable energy, it would be necessary to employ conservation and efficiency. The 26.5% possible savings for Louisville as reported in Chapter III can be achieved in many ways. Conservation and efficiency are not as much of an incentive in a high-carbon, low-cost paradigm like Louisville versus a high-cost energy market in other parts of the country. In the long term, costs of electricity from renewable energy sources will be lower than fossil-fuel generated power (Freeman & Parks, 2016), but in the short term, they will be higher. With the initially higher costs per kilowatt hour of electricity under a renewable energy paradigm, conservation and efficiency are more important during the transition.

Buildings

Conservation and efficiency measures will be needed in homes and businesses with respect to lighting, heating, cooling, and use of appliances. This can be achieved through efficiency improvements like replacing bulbs and HVAC equipment, adding insulation, sealing the building envelope, and installing or upgrading insulating doors and windows. Efficiency can also help to alleviate some of the peak demand issues discussed earlier. Conservation measures could include changing the settings on thermostats, using blinds and curtains to block incoming sunlight, using ceiling fans, turning off HVAC and opening windows when possible, using natural lighting, turning off appliances when not in use, and stopping phantom loads from appliances that are drawing power even when they are off. Incorporating efficiency into new construction is also important and is often more economical than retrofitting existing buildings. According to Lovins (2007), new buildings can be constructed that consume 50-80% less energy.

Lighting. Lighting and small appliances account for 47% of residential electricity use (Granade, at al., 2009) and offer Louisville homes and businesses a great opportunity to reduce consumption. Major improvements have been made in the efficiency of lighting for homes, businesses, industry, and street infrastructure. Sawin and Moomaw (2009) conclude that almost 10% of global electricity consumption could be eliminated simply by changing light bulbs. Daylighting incorporates the use of natural light instead of artificial light to provide light at no cost by designing buildings that use large windows, skylights, and solar tubes, and has been shown to increase sales in retail stores and productivity in industrial applications (Romm & Browning, n.d.). For example, Boeing participated in the EPA's Green Lights program that encourages companies to upgrade to more efficient lighting, and reduced the company's lighting electricity use by 90% (Romm & Browning, n.d.). Research has shown better workplace lighting can result in greater productivity when it produces better quality light while using less electricity (Romm & Browning, n.d.). Pennsylvania Power & Light, the sister company to Louisville, Gas and Electric, reduced its energy use at their drafting facility by 69% while also increasing productivity by 13% and reducing absenteeism by 25% (Romm & Browning, n.d.). Conservation measures can also save energy such as turning off lights when not in use or using motion sensors in rooms to turn off lights. Mardookhy, et al.

(2014) found that of the residents of Knoxville, TN only 64% turned off lights when not in use, 34% left outdoor lights on, and only 21% used a motion activated light. In winter when lighting is a larger percentage of the peak afternoon demand for residences and retail stores, LED lighting can cut this lighting load in half (Lazar, 2014).

Changes to lighting used in community infrastructure such as street lights and traffic lights also provide opportunity for savings. LED lights are available for traffic lights and they use 90% less energy (U. S. Department of Energy, 2004). The city of Louisville has already replaced all of their incandescent traffic lights with LED lights. Street lights can be fitted with lower wattage bulbs that produce comparable light. The city of Rijeka, Croatia replaced 80% of their street light bulbs over 10 years and reduced their electricity consumption by 3.7% while simultaneously increasing the number of street lights by 10.3% (Radulovic, Skok, & Kirincic, 2011).

Appliances. Louisville residents can reduce their energy even more by replacing old appliances. Since passage of the National Appliance Energy Conservation Act in 1987, new standards for efficiency in appliances has reduced U.S. electricity use by 88 TWh annually and these savings are expected to grow as standards become stricter (Granade, et al., 2009). The EnergyStar program operated by the Department of Energy and the Environmental Protection Agency that sets standards and provides labeling for efficient electronic devices has helped to save 159 TWh of energy through 2007 (Grenade, et al., 2009). Additional energy savings can be realized if consumers were to replace their older appliances with new ones. Mardookhy, at al. (2014) found that only 36% of residents of Knoxville, TN had an EnergyStar convection oven, 53% has an EnergyStar microwave, 64% had an EnergyStar refrigerator, and 75% had an EnergyStar computer.

Conservation measures such as unplugging phone chargers, only running dishwashers when they are full, keeping refrigerator coils and furnace filters clean, and powering down computers can also reduce energy use. Mardookhy, at al. (2014) found that while 88% of Knoxville, TN residents used the sleep mode on their computers, only 30% unplugged appliances when not in use. LG&E offers rebates for customers that purchase EnergyStar refrigerators, freezers, dishwashers, and clothes washers (LG&E, n.d.b). Continuation and expansion of this rebate program would help to encourage Louisville residents to become more efficient with respect to appliance use.

Heat pumps. Another source for energy reduction for Louisville can be achieved with heat pumps. Heat pumps extract heat from the ground, water, air and transfer it to a building (Freeman & Parks, 2016). Heat pumps run on electricity and are considered by some to be a renewable energy source because of their ability to harness energy stored in the earth, air, and water (Freeman & Parks, 2106). Air source heat pumps (ASHP) are the most common type and can use 30-40% less energy than conventional HVAC systems (U. S. Department of Energy, n.d.). Ground source, commonly known as geothermal heat pumps (GHP) have the potential to save up to 80% of energy required for heating and cooling systems in most any type of building, while average savings are in the 30-50% range (Konrad, 2014; Lund et al., 2004). It is difficult to know exactly how many heat pump systems are in service and how many are being installed annually because of the lack of accurate data (OREC, n.d.). The U. S. Department of Energy (n.d.) estimates that there are about 50,000 new geothermal heat pump installations annually, while OREC (n.d.) reports that there are about between 10,000 and 40,000 new annual installations. Lund et al. (2004), on the other hand, estimated that there were 600,000

GHP units that were installed in the country by 2004 and that about 80,000 were added each year. Navigant Research projects a 150% growth in the use of GHP technology by 2020 (Martin, 2013).

There are many examples of GHP in Louisville. One of the largest GHP installations in the United States is at the Galt House Hotel in Louisville. The system provides more efficient HVAC for 600 hotel rooms, 100 apartments, and 106,000 square yards of office space for a total area of 193,000 square yards (Lund, et al., 2004). The system uses 47 gallons of water per second from four wells at 57 ° F, providing 15.8 MW of cooling and 19.6 MW of heating capacity (Lund, et al., 2004). In 2009, Bellarmine University installed a geothermal field to heat and cool five of its buildings employing 88, 500-feet deep wells (Bellarmine University, 2009). The North Village section of the Norton Commons housing development is incorporating GHP in the 1,800 homes being built there as well as at St. Bernadette Catholic Church (Clark, 2015). While Louisville relies heavily on natural gas for heating, air conditioners are mainly electric, so there are many more opportunities for installing heat pumps to increase HVAC efficiency and save energy.

Observer effect and feedback loops. Home energy management systems can allow Louisville homeowners to monitor their usage in easy-to-read graphic forms that give them feedback on how well they are conserving their energy. There are three main types of feedback, direct, indirect, and disaggregated by end-use (Darby, 2006, p. 3). Among the many forms of direct feedback are free-standing meters or displays in buildings and homes that allow the users to see how much they are consuming at any given moment or for a recent time period (Darby, 2006). Indirect feedback can include usage information on customer’s utility bills or statistical analysis from energy consulting companies (Ehrhardt-Martinez, Donnelly, & Laitner, 2010). LG&E is piloting a direct feedback Advanced Meter Service program that is providing smart meters to 5,000 customers (LG&E, n.d.). The most sophisticated feedback comes from devices that disaggregate the information so that users can determine how much energy each of their appliances is consuming (Darby, 2006). There are a number of home energy monitoring systems available on the market that use current transducers installed on the power cords of appliances to measure the electricity used by each with the results displayed on in-home monitors or on smart phone (Weliczko, 2013). It is now even possible for homeowners to regulate their thermostats and other appliances while away from home by turning them up, down, on or off when desired (Clauser, 2015). Ehrhardt-Martinez, Donnelly, & Laitner (2010) found that the amount of electricity saved ranges from 3.8% to 12% (Figure 8). Darby (2006) found the energy savings from direct feedback ranges from 5% to 15%. If employed, feedback systems can help Louisville businesses and household to meet the 26.5% energy reduction as estimated in Chapter III.

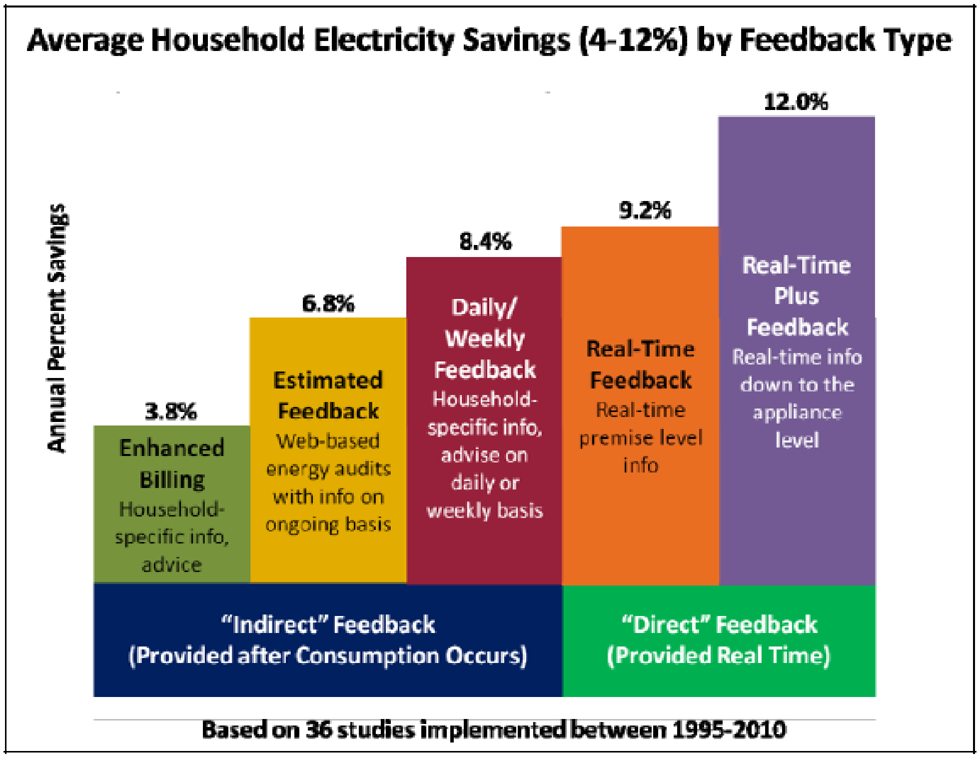


Fig. 8. Average household electricity savings by feedback type (Ehrhardt-Martinez, Donnelly, & Laitner , 2010).

Other conservation and efficiency solutions. Louisville residents and businesses will have to implement other conservation and efficiency measures to reduce demand before implementing a 100% renewable energy grid. Insulation is a very effective strategy for conserving a building's energy and making it more efficient. Insulating a building involves sealing the building envelope to keep outside air from coming in and inside air from getting out. Adding insulating materials in the walls and roof, and increasing the insulating value of windows and doors reduces the amount of energy needed to heat and cool the building. According to Brown, Southworth, & Stovall (2005), only 40% of homes are well-insulated and less than 40% of new window sales are well-insulated windows. Only 17% of windows in commercial buildings are well-insulated and only

30% of commercial buildings have roof insulation (Brown, Southworth, & Stovall, 2005). Mardookhy, et al. (2014) found that 81% of residents of Knoxville, TN reported that their house was well insulated and 70% had double-pane windows. LG&E offers rebates for replacing appliances, adding film to windows, installing heat pumps and other HVAC systems, lighting upgrades, insulating windows, making LEED certified improvements and more (LG&E, n.d.). They also offer energy audits and a demand conservation program that allows the utility to cycle off air conditioning units during peak demand periods (LG&E, n.d.). Other ways to keep a building cooler in summer and warmer in winter include painting the roof a light color to reflect heat, adding awnings to windows to block the sun, using shades or curtains, use of thermal storage materials to absorb the sun, and planting deciduous trees on the south side of the building (U.S. Department of Energy, n.d.b).

Utilities also have opportunities for efficiency. LG&E converted its Cane Run coal combustion plant to more efficient combined cycle natural gas plant, but there are many other opportunities to be more efficient in the way the company produces electricity. Electricity distribution and distribution infrastructure loses about 6% of the energy that is generated according to the EIA (2015c) and between 8% and 15% according to the International Electrotechnical Commission (n.d.). By shrinking the distance between producer and user, a reduction can be achieved in the amount of electricity lost. This is an advantage to locating solar panels on buildings. According to the International Electrotechnical Commission (n.d.), high efficiency transformers, which step up and step down electricity for long distance transmission, can save as much as 200 TWh of electricity worldwide. The use of superconducting transformers and high temperature superconducting wires will also reduce the loss of transmission (International Electrotechnical Commission, n.d.). LG&E should take steps to increase its efficiency during the transition to renewable energy. Building more efficient combustion power plants, or retrofitting existing combustion plants to be more efficient, will not be discussed here since this case study involves replacing the existing generation with renewable energy sources and therefore requires that fossil-fuel generated power stations be taken offline entirely.

Energy performance contracts can be a great tool for financing energy efficiency projects at larger businesses and institutions. The University of Louisville has worked with Siemens to make upgrades in their lighting to reduce their electricity consumption by 14%, and installed occupancy sensors that reduced energy consumption by 20-40% (Mog, 2016). Through energy performance contracts the university was able to obtain financing for over $45 million in improvements with the payments scaled to the amount of expected savings (Mog, 2016). Many businesses and residents would not qualify for this type of financing because of credit risk considerations, but it works well for government backed organizations and larger corporations (personal communication Michael Azzara, August 19, 2014). Government guarantees and incentives for energy performance contracts for businesses, residents and non-profits could greatly expand the use of this service.

Transportation

The average annual U.S. vehicle miles traveled (VMT) per household increased from 12,500 to 21,500 between 1969 and 2001 and the average number of vehicles per household increased from 1.2 to 1.9 during that period (Brown, Southworth, & Stovall, 2005). Conservation and efficiency measures will also be needed in electric vehicle use so that less electricity is used per mile, but also so that the total number of vehicle miles traveled (VMT) can be reduced. As reported in Chapter III, Louisville can achieve a 15.8% reduction in VMT by 2050 through measures such as combining trips, car pooling, ridesharing, using alternative forms of transportation such as public transportation and bicycling, and avoiding driving by telecommuting or staying at home for the evening. There are a number of ways to reduce electricity consumption with electric vehicles. Efficiency improvements are sure to happen over time as newer models are designed. Louisville will need to implement conservation measures in order to reduce VMT and the number of vehicles through the use of alternative forms of transportation such as public transit, bicycling, walking, and telecommuting. There are a number of factors that can encourage this. Brown, Southworth, & Stovall (2005) report that VMT can be reduced by 5 – 12 percent by 2050 through changes in land use patterns alone. Investment in public transportation and bicycle infrastructure increased the use of alternative forms of transportation in cities like Boulder, CO, Cambridge, MA, Portland, OR, and Davis, CA (Henao, et al., 2014) and is also possible in Louisville. One way to achieve a reduction in VMT is to work towards a change in the mode of transportation from automobiles to public transportation and bicycling. The number of people using alternative modes of transportation (mode share) in Boulder, Colorado (Figure 9) increases along with the amount of cumulative investment in alternative transportation infrastructure (cumulative enhancement). Louisville would need to put itself on a similar trajectory.

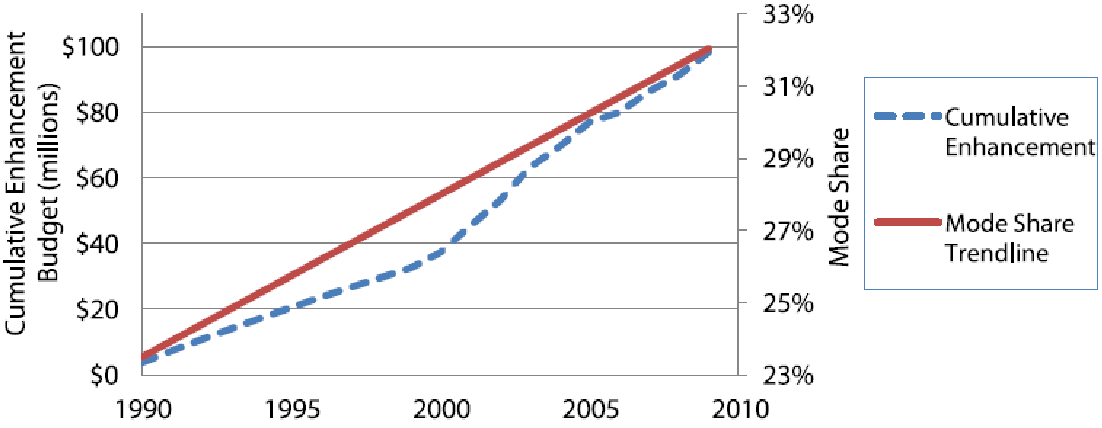


Fig. 9. Boulder Colorado cumulative investment in alternative transportation infrastructure compared with increases in mode share (Henao, et al., 2014, p.70).

Grade-separated bicycle and pedestrian paths, bicycle lanes, cycle-tracks, on-street bicycle routes, light-rail systems, bus rapid transit (BRT), high-frequency bus routes, more buses, transit stop improvements, transit priority at signalized intersections, and land development restrictions are all ways to enhance shifts in mode share (Henao, et al., 2014). As an example, Boulder, Colorado was able to increase its non-auto modes by 8.5% over twenty years (.45% average per year) while the national average experienced a 1.1% decrease (Henao, et al., 2014). Henao, et al. (2014) also admit that mode share shifts tend to result from a combination of forces that cannot simply be attributed to investments in infrastructure made by municipal transportation budgets. There are also policies that can encourage mode share shifting such as taxes to fund alternative transportation improvements, changes in parking policy, accessing other sources of infrastructure funding, and diverting motor vehicle project funding towards non-auto infrastructure (Henao, et al., 2014). Complete Street design is methodology for making streets safe for all modes of transportation and can go a long way to help increase transit and bicycle commuting (Laplante & McCann, 2008).

In order for Louisville to achieve a 0.45% per year shift in transportation modes from driving cars to alternative forms of transportation, many changes will need to be implemented. The city currently has plans to add bus rapid transit (BRT) along the Dixie Highway corridor that would use special lanes and transit priority at signalized intersections. An expansion of BRT to other corridors like Preston Highway, Taylorsville Road, Broadway, Shelbyville Road, and Poplar Level Road should also be implemented. Additionally, TARC should put in place more high-frequency bus routes similar to their "Five at Fifteen" initiative that guaranteed a bus every fifteen minutes on the five most used routes (TARC, 2008). The transit authority's T2 (Transportation Tomorrow) light rail system plans should be revisited in hopes of implementation by 2050 (TARC, 2008). Bus stops should be enhanced to use GPS capability that shows when the next bus will arrive. More shelters that provide protection for passengers during inclement weather should be constructed. Replacement of all internal combustion engine buses with all-electric buses can be completed by 2050. These improvements will require funding from the city but also the state and federal government. TARC, unlike many other transit systems in the U. S., does not have a permanent funding stream from state government (TARC, 2008). Downs, at al. (2013) report that Kentucky ranks 43rd in the nation in per capita transit expenditures at $0.34 per person in 2011, or $1.5 million for 4.4 million people.

In order to reduce the number of vehicle miles traveled in the city and therefore reduce the amount of solar power necessary for fueling vehicles, better infrastructure for supporting safe bicycling will be needed. In addition to more on-street bike lanes and routes, the city will need more dedicated bicycle and pedestrian paths. Humana, Inc. (2008), one of the city's largest employers, implemented a bike sharing program called Freewheelin that is operated by the non-profit Bikes Belong who provides similar programs in Denver and Minneapolis/St. Paul. The program provides free bicycles for Humana employees at their downtown location, and over 2,500 employees have signed up for the program (Humana, 2008). City government has plans to implement a bike share program where people can rent the bikes using CycleHop, a company that operates similar programs in Phoenix, Atlanta, Orlando, and Santa Monica (Ryan, 2015). The city is seeking sponsorship for the program and hopes to have it in place in 2016 (Ryan, 2015). More employers could implement bike share programs similar to the program used by Humana.

Sidewalks need to be built along many of the suburban corridors that are serviced by transit (TARC, 2008). Land use planning and regulations can help to encourage people to live closer to their work place, stores, doctor's office, dentist, restaurants, movie theaters, etc. in order to increase the use of walking as a mode of transportation and increase the mode shift.

Similarly, more regulations are needed to curb the urban sprawl that stretches transit thin and increases commute miles for cars. Infill development needs more incentives so that brownfields and abandoned space in the urban core can be revitalized. Parking prices should be raised to discourage driving and encourage mode shifts (TARC, 2008).

Other Renewable Energy Sources

As noted in Chapter III there is the potential for 1.2 TWh of locally-generated renewable electricity annually from sources other than solar. The following is a summary of the renewable energy options found in this study.

Bioenergy

The use of bioenergy, energy produced from plants, will not contribute additional greenhouse gases to the atmosphere under the right conditions (Tilman, et al., 2009). According to Tilman, et al. (2009), “biofuels done right can be produced in substantial quantities.” In order to be truly renewable, biofuel sources of energy must be derived from plant materials produced without fossil fuels and with little or no competition with food production (Tilman, et al., 2009). Bioenergy can include burning plant material to produce electricity, converting plant material to fuel to run in vehicles, extracting methane from decomposing plant material for electricity production or to run vehicles, burning municipal waste to create electricity (MSW), or extracting methane from landfills (LFG). Using the assumption that 100% of the vehicles will be electric in a renewable energy future, liquid biofuels were not considered in this study, instead biomass sources were only considered for their electricity generating potential.

According to Mai, et al., (2012b) biomass supply is significant in the Great Plains, Great Lakes, Central, and Southeast regions of the United States. Their computer modeling which projected future energy generation under a 90%-renewable by 2050 scenario, determined that there will be a reliance on bioenergy that is sourced from 14%

urban waste, 18% lumber and paper mill waste, 11% forest residue, 30% agricultural residue, and 27% dedicated crops” (p. 3-5).

Electricity produced from biomass can be used as base-load or dispatchable power, an important component Louisville’s grid will be heavily dependent upon solar Augustine, et al. (2012). Bioenergy technologies include those that directly combust biomass to produce steam for electricity generation and those that convert biomass to an intermediate gas or liquid that is then burned to produce electricity (Augustine, et al., 2012). Conversion processes include thermal gasification where the organic matter is heated to the point where it becomes a gas, thermal pyrolysis where heat is used to convert the material to a liquid, and anaerobic digestion that uses biological means to decompose the material for the purpose of creating methane (Augustine, et al.). One of the concerns surrounding the generation of bioenergy is that it will compete with other existing uses for biomass like composting, mulching, production of wood products, or consumption as food for livestock or people (Searchinger, 2015). There are also concerns that an increase in the burning of wood will endanger forested areas and the creation of particulate matter pollution. These concerns can be alleviated by employing restrictions on the sources of the biomass and with pollution control devices to remove the particulate matter. Carbon dioxide emissions from combustion are not seen as a concern if the plant matter is being cyclically replaced with new plants to recapture the carbon.

There are many opportunities for the production of electricity from bioenergy in Kentucky. Lopez, et al. (2012) estimate that Kentucky can technically produce 8,332 GWh of electricity annually from bioenergy. There are a number of ways to directly convert biomass to electricity including direct combustion (co-firing, dedicated combustion, or combined heat and power (CHP)) and gasification (pyrolysis or anaerobic digestion) (IEA, 2007). Co-firing involves mixing biomass with coal for combustion in a coal-fired power plant. The IEA (2007) notes that when 5-10% of biomass is introduced, only minor changes in the handling equipment is needed and there “the boiler is not noticeably derated,” however, when the biomass exceeds 10% “then changes in mills, burners and dryers are needed. (p. 2).” Dedicated combustion of biomass requires a plant built or retrofitted for that purpose where, like co-firing, the materials are burned to produce steam in a boiler that runs a turbine (IEA, 2007). CHP uses this direct combustion method to generate electricity while also providing warmth for a facility using the excess heat from the boiler. Gasification using pyrolysis involves heating the plant material to produce biogas that runs gas combustion turbines. Anaerobic digestion is the slow process of allowing organic material to ferment with the help of bacteria to produce biogas (IEA, 2007). While any combination of these methods could be used during the transition to a 100% renewable energy grid, a long-term solution that avoids particulate pollution from direct combustion is important in order to be sustainable.

Dedicated crops. Lambert (2008) estimates that 14 species of trees are suitable for being raised as sources of biomass on abandoned Kentucky coal mines. Anderson (2009) found that in Kentucky there are many fast-growing trees that make excellent energy crops, since they grow back after being cut off close to the ground. Varieties that produce the most energy in the shortest time include poplar, willow, sycamore, sweetgum, and cottonwood (Anderson, 2009). Milbrandt (2005) estimated that Louisville and its eight surrounding counties could produce up to 35,000 dry tons of biomass annually from dedicated crops like switchgrass, willow trees and hybrid poplar trees. The dedicated crop production (in dry tons) (Table10) was determined for the states of Indiana and Kentucky and the eight county region that includes Jefferson County and the surrounding counties of Oldham, Shelby, Spencer, Bullitt, Hardin in Kentucky and Jefferson, Clark, and Floyd in Indiana.

Table 10. Biomass generation from dedicated corps of switchgrass and trees (Milbrandt, 2005).

Crop	Eight-county region	Kentucky	Indiana
Switchgrass	18,000-105,000 tons	1,822,000 tons	1,609,000 tons
Willow or hybrid poplar trees	27,000-120,000 tons	1,433,000 tons	1,248,000 tons

Urban wood waste. Beshear (2008) estimates that annually there are 340,000 tons of urban tree debris available in the state for creating bioenergy. Storm debris, and diseased trees and limbs removed from city parks in Louisville produces 600-1,000 tons of waste annually and is currently sold to Recast Energy Louisville, LLC for a combined heat and power facility that provides energy for companies in the city's industrial Rubbertown area (Austin, 2012; City of Louisville, 2013; Recast Energy, n.d.). The National Renewable Energy Laboratory (2015) estimates at least 50,000 dry tons of urban wood waste is available annually from Louisville to produce electricity.

Lumber mill waste. The National Renewable Energy Laboratory (2015) categorizes mill waste into primary and secondary sources. Primary sources are from industries that process trees into lumber and secondary sources process lumber into products (NREL, 2015a). Mill residues and bark from primary mill sources and wood scraps and sawdust from secondary sources can be used to produce biogas. According to Beshear (2008), sources for bioenergy in Kentucky include "residues from charcoal, railway ties, cant and pallet industries, and potentially low valued factory lumber" (p. 14). NREL (2015a) estimates that Louisville and the surrounding counties can produce at least 43,000 tons of secondary waste per year. The conservative lower limit of 43,000 tons would generate 47.3 MWh of electricity annually using conversion rates provided by Augustine, et al. (2012). Primary waste estimates from NREL (2015a) were very low and determined to not be a significant source of biomass energy for Louisville.

Industrial, commercial, and institutional food waste. Food processing waste can be sourced from hospitals, schools, universities, jails and prisons, restaurants, grocery stores, and food processing facilities located in and around the city of Louisville. The Metro Solid Waste Management District has undertaken a pilot wet-dry program to collect biodegradable waste from the Central Business District (Louisville Metro Public Works, n.d.). Currently the waste is being composted, but if the district expands the program city-wide, then it is possible that excess waste could be used for electricity generation. The city's sustainability plan calls for a 90 percent diversion of solid waste by 2042 and this could create more bioenergy potential as beneficial uses for waste are sought (Louisville Metro Government, 2013). Industrial and commercial waste could provide bioenergy as well. Nature's Methane, LLC, a subsidiary of STAR Energy Holdings, LLC has plans to build anaerobic digesters within the city of Louisville for the purpose of converting fats, oils and other organic material from Heaven Hill's distillery (Bruggers, 2015b). The distillery currently creates 75 million gallons of stillage (the grain residue left from the production of alcohol) annually and is expected to increase to 100 million

(Bowling, 2015). Additionally, Nature's Methane wants to partner with other food processing facilities, restaurants, groceries, and businesses to supply materials for their digesters (Estes, 2015). NREL (2015a) estimates that Louisville and the surrounding counties can produce at least 2,500 tons of industrial, commercial and, institutional food waste per year.

Manure. Manure and animal bedding waste originates from nearby horse farms, stables at Churchill Downs, the Louisville Zoo, the University of Louisville research facilities, the Bourbon Stock Yards, and about 3,500 small farms in the vicinity of the city. The U.S. Department of Agriculture (2015) 2012 Census of Agriculture recorded over 3,500 farms in Jefferson County and the eight surrounding counties of Oldham, Shelby, Spencer, Bullitt, Hardin in Kentucky and Jefferson, Clark, and Floyd counties in Indiana with about 137,000 cattle, calves, hogs, pigs, and poultry (Table 11).

Table 11. 2012 census of cattle, calves, hogs, pigs, and poultry in vicinity of Louisville, Kentucky.

		Cattle and calves		Hogs and pigs		Poultry		Total	
County	St.	farms	animals	farms	Animal	farms	animals	farms	animals
Jefferso	KY	113	2,555	4	11	55	1,159	172	3,725
Oldham	KY	128	7,953	3	16	50	1,038	181	9,007
Bullitt	KY	225	6,246	18	1,479	67	1,380	310	9,105
Shelby	KY	661	32,737	20	142	152	6,057	833	38,936
Spencer	KY	291	9,001	-	-	66	1,354	357	10,355
Hardin	KY	752	31,819	32	6,779	166	3,028	950	41,626
Jefferso	IN	289	6,899	24	*1,770	62	1,193	352	9,396
Clark	IN	197	6,228	9	280	39	*727	231	6,937
Floyd	IN	_	-	6	*1,036	25	-	-	-
		2,749	109,908	116	11,513	682	16,365	3,510	137,022

*for these figures actual numbers were not disclosed in census so as to "avoid disclosing data for individual farms" so estimates were used. Source U.S. Department of Agriculture (2015).

Agricultural residues. Many farms use leftover plant materials for fertilization of the soil, but many also have excess crop residues that could be used for biogas production. NREL (2015a) estimates that Louisville and the surrounding counties could provide from 80,000 to 300,000 tons of such waste annually.

Sewage. The Metropolitan Sewer District (MSD) operates four anaerobic digesters at their Morris Forman Sewage Treatment Plant that produce methane gas that is currently used to power dryers that turn the solid wastes into commercial fertilizer. The facility produces enough gas to create 57.4 GWh of electricity annually based on numbers supplied by Robert Bates, MSD Biosolids Administrator (personal communication, July 30, 2015). The District is considering discontinuing the fertilizer program because of concerns about costs and due to equipment degradation (Bruggers, 2014b). Discontinuation of the program would free up the methane to be used to generate electricity. Brian Zoeller (attorney for STAR Energy, says his client is interested in constructing biodigesters to convert the sewage to methane for sale to Louisville Gas & Electric.

Landfill gas (LFG). According to the EPA (2016a), landfills are the third largest source of human-related methane emissions in the United States, accounting for 18 percent of these emissions in 2013. That methane can be used to generate renewable energy. According to Marie Burnett (personal communication, June 5, 2015), Senior District Manager of Waste Management, the company's Outer Loop Landfill, located in Louisville, generates about 6,800 scfm of LFG. According to the EPA (2013) there are 19 "candidate" landfills in Kentucky that are capable of producing LFG. Candidate landfills have already been accepting waste, or have been closed for five years or less, have at least 1 million tons of waste, and are not currently producing landfill gas for use. These sources are not included in this study, but these landfills could potentially provide additional renewable energy for the city of Louisville in the future.

Table 12. Bioenergy resources Louisville, Kentucky and surrounding counties.

Bioenergy resource	Characteristics	Local sources	Comments	Quantity
Urban wood waste	Yard waste, tree trimmings, site-clearing wastes, pallets, construction and demolition waste.	Tree services, Metro yard waste, construction companies, waste haulers, used pallets.	Diverted from landfills, Jefferson County only.	At least 50,000 dry tons per year.
Agricultural residues	Unused plant parts from corn, soybeans, and other crops.	Limited to small number of farms in surrounding counties.	Assumes 65% needed for soil fertility.	80,000 to 300,000 dry tons per year.
Forest residues	Unused portion of cut trees not used for commercial purposes.	Silvicultural activities in surrounding counties.	Assumes 35% of logging residues and 50% of other forestry residues are left for soil fertility.	25,000 to 90,000 dry tons per year.
Industrial, Commercial, and Institutional wastes	Waste from food processing, wholesalers, and institutions serving food.	Distilleries, grocery stores, hospitals, schools, prisons, nursing homes, etc.		From 2,500 to 9,000 tons per year.
Manure	Animal waste from cows, chickens, hogs.	Limited to small number of farms in surrounding counties.		Up to 4,500 tons per year.
Primary mill residues	Mill residues and bark generated at manufacturing plants.	Limited to small number of facilities.	Most of this is currently utilized by the factories.	Less than 25,000 dry tons per year.
Secondary mill residues	Wood scraps and sawdust from woodworking shops.			At least 43,000 dry tons per year.
Wastewater treatment	Sewage and storm drain waste.	MSD, surrounding county sewage treatment		At least 7,000 tons per year.

		facilities		
Landfill gas	Organic waste in landfills.	Outer Loop landfill, others in vicinity.	"Candidate" landfills as determine by EPA not included.	Up to 4,500 tons per year.

Bioenergy resources were determined using maps provided by the NREL (2015a) and Table 12 summarizes the total bioenergy potential for Jefferson and the surrounding counties. These locally available sources could be used to produce electricity. There are both dry sources (urban wood waste, agricultural residues, forest residues, primary and secondary mill residues) and wet sources (industrial/commercial/institutional food waste, manure, wastewater, and landfill gas).

Geothermal

Kentucky has no conventional heat-flow data for which to assess potential hydrothermal or enhanced geothermal electricity generation systems (MIT, 2006; Short, 2011) and is presumed to have low potential for either form. Enhanced geothermal systems (EGS) that involve drilling thousands of feet into the earth to access hot dry rock that can be used to produce steam-generated electricity when water is introduced, actually do have potential. Lopez, et al. (2012) estimate that Kentucky can technically produce 484,659 GWh of electricity annually from EGS. Since this technology is not widely used yet, these electricity generation numbers will not be considered here, but EGS will likely provide some electricity to Louisville in future years. While many homes and businesses in Louisville use natural gas for heat, geothermal heat pumps (GHP) and air source heat pumps (ASHP) still have potential for reducing electricity use in Louisville. For discussion of GHP specifically see “efficiency and conservation” below.

Table 13. Summary of potential new hydropower resources in Region 5 (Kao, et al., 2014).

HUC04	HUC04 name	# of stream-reaches	Potential capacity (MW)	Potential energy (MWh)	Average head (ft/reach)	Average flow (cfs/reach)	Average storage (ac-ft/reach)	Average residence time (days)
0501	Allegheny	87	424.2	2,323,264	23.5	3,282	5,918	2.4
0502	Monongahela	111	371.1	2,008,181	31.5	1,570	3,258	1.9
0503	Upper Ohio	24	86.9	471,331	25.7	3,260	9,551	5.8
0504	Muskingum	18	62.7	351,578	17.8	2,898	7,259	2.3
0505	Kanawha	174	954.0	5,293,479	37.2	2,069	6,596	3.6
0506	Scioto	12	52.0	268,306	16.6	3,752	19,652	2.7
0507	Big Sandy–Guyandotte	49	122.8	617,627	40.0	991	15,593	7.0
0508	Great Miami	26	61.4	324,322	21.8	1,902	8,394	5.8
0509	Middle Ohio	9	13.7	68,784	28.6	760	14,666	12.6
0510	Kentucky–Licking	41	160.7	764,354	33.0	1,980	17,057	8.4
0511	Green	23	76.1	386,285	23.6	2,256	17,995	8.0
0512	Wabash	66	445.9	2,390,224	22.7	4,260	51,803	17.2
0513	Cumberland	50	195.7	960,886	45.3	1,498	17,656	14.1
0514	Lower Ohio	9	16.0	74,987	26.1	1,180	10,634	5.3

Hydroelectric

Kao et al. (2014) identified 699 stretches of waterways (stream reaches) in the region of the country that encompasses the city of Louisville (Region 5 includes parts of Illinois, Indiana, Kentucky, Ohio, Pennsylvania, Tennessee, North Carolina, Maryland, Virginia, West Virginia, and New York). There are 14 waterways (Table 13) identified by Kao, et al. (2014) in states within Louisville’s region for new hydropower generation.

A map (Figure 10) of the location of potential for new hydropower generation in Region 5 was prepared by Kao, et al. (2014) and shows ample resources available. During the parts of the year when there is more rainfall, hydropower in the region has the potential to provide a significant amount of baseload electricity for Louisville, especially if transmission capacity is increased and regional trading of electricity is implemented. Kao, at al. (2014) estimate that Kentucky alone has the potential for 675 MW of new hydro power that could generate 3,301 GWh per year of electricity. Lopez, et al. (2012) estimate that Kentucky can technically produce 4,255 GWh of electricity annually from hydropower. There are 33 dams in Kentucky that do not currently have hydroelectric turbines. If these were harnessed, the state's hydro energy would be quadrupled (Estep, 2015). Four of those dams are the top four non-powered dams in the nation if ranked by potential energy production and each has at least a 60 MW capacity (Estep, 2015).

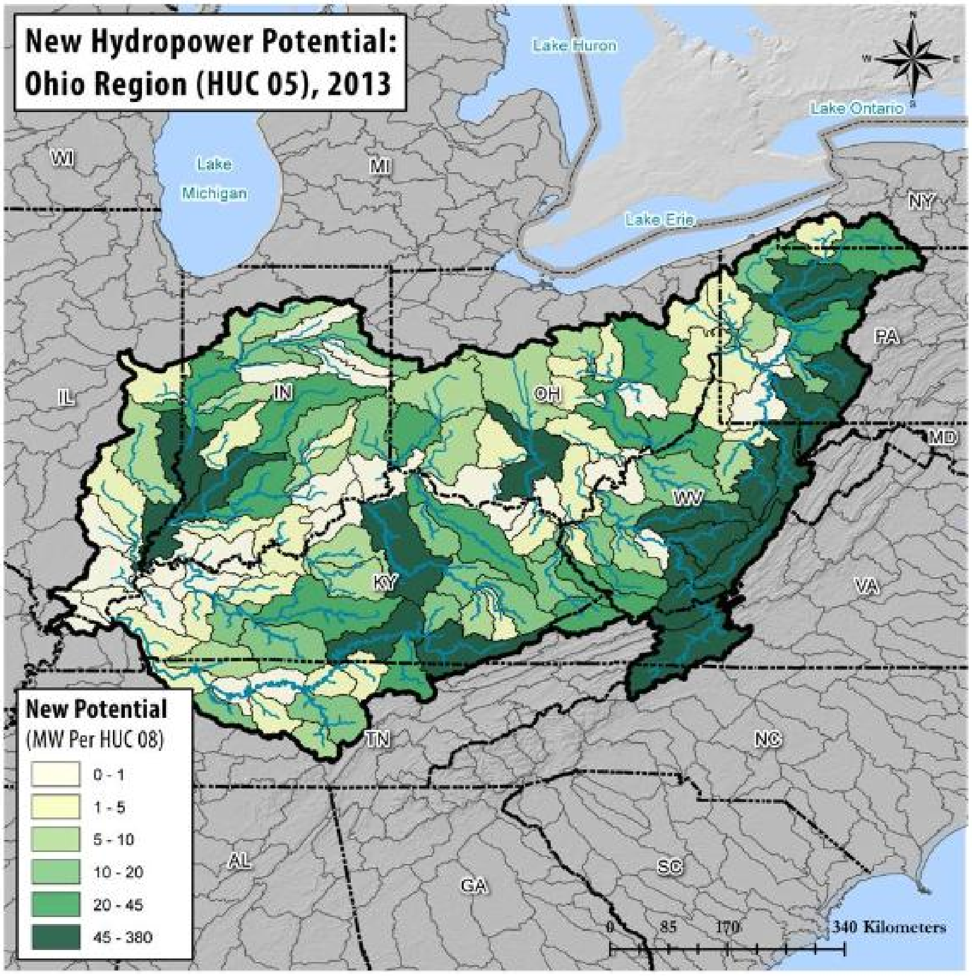


Fig. 10. Potential new hydropower capacity in Region 5 (Kao, et al., 2014).

Wind

Jacobson, et al. (2014a) indicate that 8.5% of Kentucky's electricity could be generated by wind by 2050, but this is not based on any actual wind data. Lambert (2008) estimates there are 19 abandoned coal mining sites in Kentucky that are suitable for utility-scale wind turbines. Lopez, et al. (2012) used data to estimate that Kentucky can technically produce 147 GWh of electricity annually from wind. Differing amounts of wind energy can be harvested at varying heights across the landscape depending upon the prevailing wind patterns and speeds for a given location. Optimum turbine height is determined based on measurements of those prevailing winds. According to Bailey, et al. (2012), Kentucky has a potential installed capacity of 760MW, with 61 MW at hub heights up to 80 meters and 699 MW at hub heights up to 100 meters. This calculation falls within the range of wind potential determined by the USDOE (2008) which estimated that Kentucky's wind capacity is between 100 and 1,000 MW.

Energy Storage

As noted in Chapter III, Louisville's projected 668,646 vehicles will be able to provide 19.5 GWh of storage capacity amounting to 0.1% of the total projected amount of generating capacity needed for the city. This V2G storage, as described below, will only be a part of the storage requirements needed for the city. There is little research available to help determine the amount of storage needed for an entire city like Louisville. Martin & Crawford (2015) note that once the generating capacity of the grid approaches 50% renewable, battery storage will be needed to address intermittency and to eventually provide some nighttime base-load energy. Modeling performed by Mai et al. (2012a) projects that about 10% of generating capacity would need to be derived from storage under their 85% renewable energy scenario. Presumably a 100%-renewable energy future would require a larger percentage of storage capacity. Storage requirements could be implemented by LG&E in different forms and at various places along the grid including home batteries, utility scale batteries, compressed air energy storage (CAES) in power plants, pumped hydro storage, and V2G.

In addition to providing night-time electricity, storage can be used for counteracting the intermittency of renewable energy, can help to reduce congestion on the grid, and allows utilities to avoid or defer transmission and distribution upgrades (U.S. Department of Energy, 2009). Ninety-five percent (23.4 GW) of existing storage in the United States (Figure 11) is pumped hydroelectric, while five percent (1.2GW) is available from thermal storage, batteries, flywheels and compressed air.

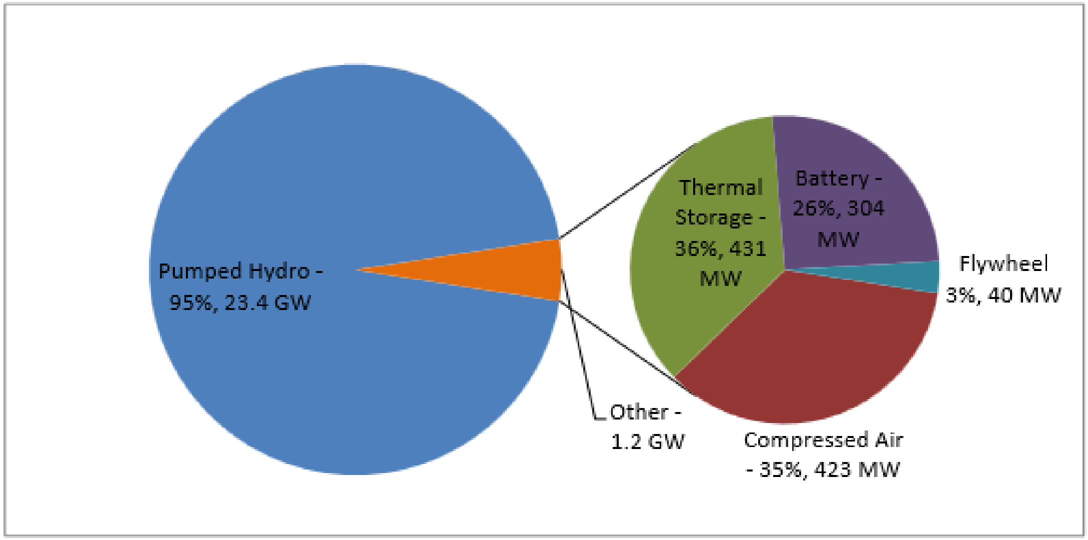


Fig. 11. Capacity of US grid storage projects (including announced project; U. S. Department of Energy 2013).

Batteries in EVs (V2G)

The part of smart grid technology that allows for energy to flow and be measured in two directions also allows for energy stored in batteries to flow back onto the grid. Energy flowing from batteries in vehicles to the grid is referred to as V2G. V2G has the potential to add an incredible amount of generating capacity to the grid once PEV penetration reaches a significant level. For example, Kempton & Tomic (2005) estimate that when just 25% of U. S. vehicles have been replaced with electric vehicles, if they were all discharged simultaneously, they could provide a generating capacity equal to that all of the current power plants. As shown in Chapter III, V2G has the potential to add 19.5 GWh of energy storage to the grid in Louisville, enough electricity to power 21,392 homes for one month.

V2G could also be used to help with the ramping issue discussed in Chapter I that arise when utilities have to ramp up production to meet fluctuations in demand and down in response to surges in solar production. If LG&E had the ability to control the timing of the discharge from car batteries, then these ramping problems could be mitigated. Milligan et al. (2012) used modeling to show that electric vehicles can be charged at night under the control of the utility by using special price incentives in markets that have non-solar sources of alternative power.

The 19.5 GWh total storage capacity of Louisville's projected 668,646 vehicles amounts to 0.2% of 12,792 MWh total projected solar electricity generation (Table 7). Because this is much smaller than the 10% projected by Mai et al. (2012a) this will not be sufficient to meet all of the storage needs in the future especially when accounting for energy reserved for operating the vehicles. Having a diversity of storage sources and bioenergy electricity production capacity will be necessary to enhance the stability of the grid.

Batteries in Homes

For the last several decades, it has been possible for homes to convert to solar energy including battery storage, which allowed the owners to be "off the grid." Most of those systems were installed because of lack of access to the grid or if net metering of solar power was not allowed in the area. Batteries add cost to a solar configuration so, in many cases, these systems are not preferred when a grid tie is available. But in the absence of another baseline source of energy to provide electricity through the night, batteries are essential. There are a plethora of batteries available, each with their own specifications regarding operation, maintenance, cost and environmental impacts. As one example, Tesla Energy released their Powerwall Home Battery in April 2015 with options for a 10 kWh or 7 kWh model (Russell, 2015). The company touts affordability and reliability as main selling points for the batteries that can be connected together for increasing capacity (Russell, 2015). Because of the newness of the technology, a full life-cycle assessment has not been completed for the Tesla Powerwall. Sunverge Energy announced in August 2015 the sale of 165 batteries to the local utility in Glasgow, Kentucky for the purpose of storing energy during time of low demand and releasing it at times of peak demand (PR Newswire Association, 2015). The batteries are located at the homes of 165 of their customers, but company remotely manages the storage and usage of the energy "as if from a single, fleet-level Virtual Power Plant (VPP)" that can provide dispatchable electricity when needed (PR Newswire Association, 2015). Most of the systems that Sunverge sells are for the purpose of storing solar energy. To meet the energy storage demands of the future, many homes in Louisville will also need to have batteries. LG&E can incentivize these through time-of-day pricing or can purchase them as did the Glasgow Electric Plant Board.

There are a number of environmental impacts of battery production and use. For example the production of nickel metal hydride (NiMH) batteries emits acidifying substances (Nordelof, et al., 2013). Toxins from the production and use of the Nissan Leaf that uses lithium ion batteries were tested by Nordelof (2013) and resulted in more than an 80% increase in human toxicity when compared to two internal combustion engine vehicles. These human toxicity impacts are only realized if there is improper disposal of the batteries at the end of their life. There are also environmental and health impacts from the mining of copper, nickel, lithium, and rare earth metals needed to make the batteries (Nordelof, 2013). Von der Boscher, et a. (2005) performed a life cycle assessment (LCA) of five types of batteries used in EVs and found that they vary in their levels of environmental impacts (Figure 12). The LCA process assigns a score based on the environmental impacts from the production, use, and disposal of the batteries. The lead-acid battery is assigned the baseline environmental score of 100 and the others are scored based on that as a means of comparison. It is important to note that the use of fossil fuels contributes to these environmental impacts because the impacts are calculated using the current mix of electricity production. Once a complete conversion to renewable energy sources is achieved these environmental impacts will decrease some. Additionally, Nordelof (2013) note that when the environmental and health impacts of fossil fuel consumption are included in the analysis, electric vehicles are shown to have lower impacts in total.

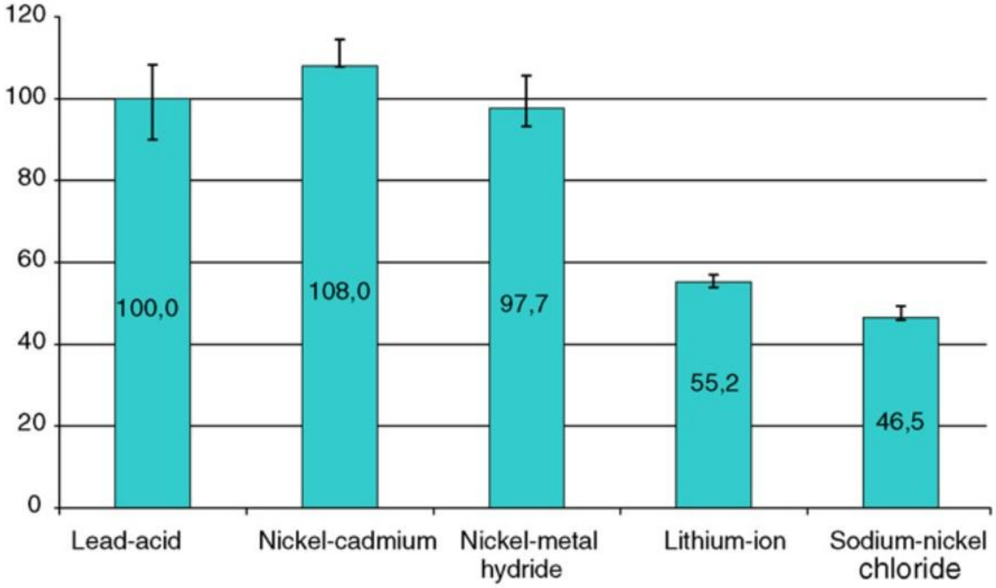
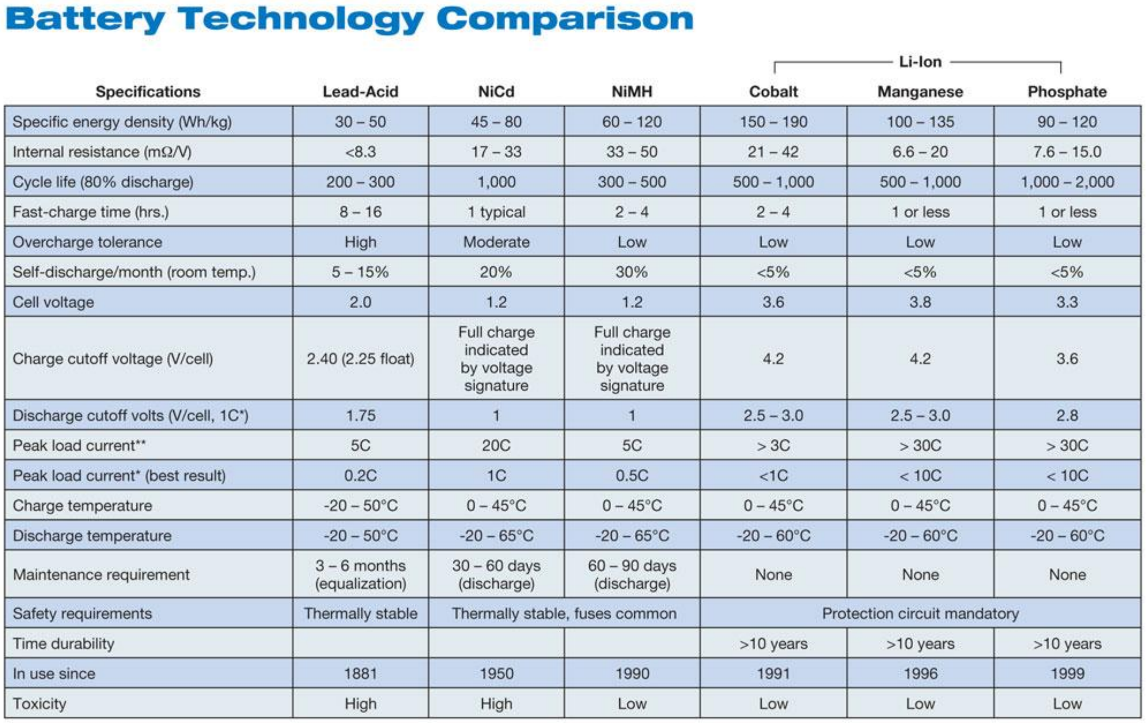


Fig. 12. Comparison of environmental impacts of five EV batteries using LCA (Von der Bossche, et al., 2005, p. 918).

Batteries have a number of limitations that must be addressed in addition to environmental impacts. Some batteries may lose storage capacity over time more quickly if they are deeply or shallowly discharged in a typical charge-discharge cycle (Carnegie, Gotham, Nderitu, & Preckel, 2013). Efficiency is also an important consideration since a low level of efficiency can amount to a significant amount of energy lost over time. Because of these factors, batteries are deemed to be at the end of their useful life when they no longer meet the daily travel needs of drivers (Saxena, Le Floch, MacDonald, & Moura, 2014). Because of this and the fact that drivers each have their own daily driving habits, it is hard to determine the precise useful life of the typical electric vehicle's batteries. For example, Saxena, Le Floch, MacDonald, & Moura (2014) found that even when batteries were at 50% of their capacity, they still met the daily travel needs of 82-85% of the drivers. Mikael Cugnet reported in a speech to the American Chemical Society (2013) that EV batteries can last from 5 – 20 years before needing to be replaced. An increase in the availability charging stations has been shown to increase the useful life of the batteries (Saxena, Le Floch, MacDonald, & Moura, 2014). The older technologies for batteries like lead acid and sodium sulfur are less efficient but better understood than the newer technologies that include advanced lead acid batteries, sodium nickel chloride batteries, lithium ion batteries, sodium ion batteries (Carnegie, et al., 2013). Additionally, some batteries emit toxic fumes and must be stored away from living spaces. A comparison of various batteries (Table 14) available today and their specifications shows that there are many options available. Louisville homeowners will need to become more aware of the types of batteries available and how they can be used to store energy for transportation or home use.

Table 14. Comparison of battery technologies (BatteryUniversity.com, n.d.).



Battery Technology Comparison

				Li-Ion		
Specifications	Lead-Acid	NiCd	NiMH	Cobalt	Manganese	Phosphate
Specific energy density (Wh/kg)	30 – 50	45 – 80	60 – 120	150 – 190	100 – 135	90 – 120
Internal resistance (mΩ/V)	<8.3	17 – 33	33 – 50	21 – 42	6.6 – 20	7.6 – 15.0
Cycle life (80% discharge)	200 – 300	1,000	300 – 500	500 – 1,000	500 – 1,000	1,000 – 2,000
Fast-charge time (hrs.)	8 – 16	1 typical	2 – 4	2 – 4	1 or less	1 or less
Overcharge tolerance	High	Moderate	Low	Low	Low	Low
Self-discharge/month (room temp.)	5 – 15%	20%	30%	<5%	<5%	<5%
Cell voltage	2.0	1.2	1.2	3.6	3.8	3.3
Charge cutoff voltage (V/cell)	2.40 (2.25 float)	Full charge indicated by voltage signature	Full charge indicated by voltage signature	4.2	4.2	3.6
Discharge cutoff volts (V/cell, 1C*)	1.75	1	1	2.5 – 3.0	2.5 – 3.0	2.8
Peak load current**	5C	20C	5C	> 3C	> 30C	> 30C
Peak load current* (best result)	0.2C	1C	0.5C	<1C	< 10C	< 10C
Charge temperature	-20 – 50°C	0 – 45°C	0 – 45°C	0 – 45°C	0 – 45°C	0 – 45°C
Discharge temperature	-20 – 50°C	-20 – 65°C	-20 – 65°C	-20 – 60°C	-20 – 60°C	-20 – 60°C
Maintenance requirement	3 – 6 months (equalization)	30 – 60 days (discharge)	60 – 90 days (discharge)	None	None	None
Safety requirements	Thermally stable	Thermally stable, fuses common		Protection circuit mandatory		
Time durability				>10 years	>10 years	>10 years
In use since	1881	1950	1990	1991	1996	1999
Toxicity	High	High	Low	Low	Low	Low

Home batteries will likely expand in use as the price of batteries fall and as consumers choose to go off-grid for energy independence and environmental reasons, or as consumers take advantage of time-of-day pricing that will make nighttime electricity more expensive.

Pumped Storage in Hydroelectric Reservoirs

Electricity can be stored in the form of water by pumping water into higher elevation reservoirs using surplus wind and solar production to be stored until needed. When there is a shortage of wind and solar, the water is then released to spin turbines that generate electricity (Figure 13). This is not an option with run-of-the-river hydro stations that rely on the current of the waterway to spin the turbines unless there are associated storage reservoirs. Pumped storage is the largest form of energy storage for electricity in the U.S. according to Carnegie et al. (2013). The Federal Energy Regulatory Commission, (FERC) (2014), has seen an increase in the number of applications for permits to construct new pumped hydro facilities in recent years. For example, there is currently a proposal to construct a 1,000 MW pumped storage project in Maysville, Kentucky using an abandoned mine for a closed-loop facility (Toncray, 2012). A closed-loop system is not connected to a waterway, but simply moves water back and forth between two reservoirs.

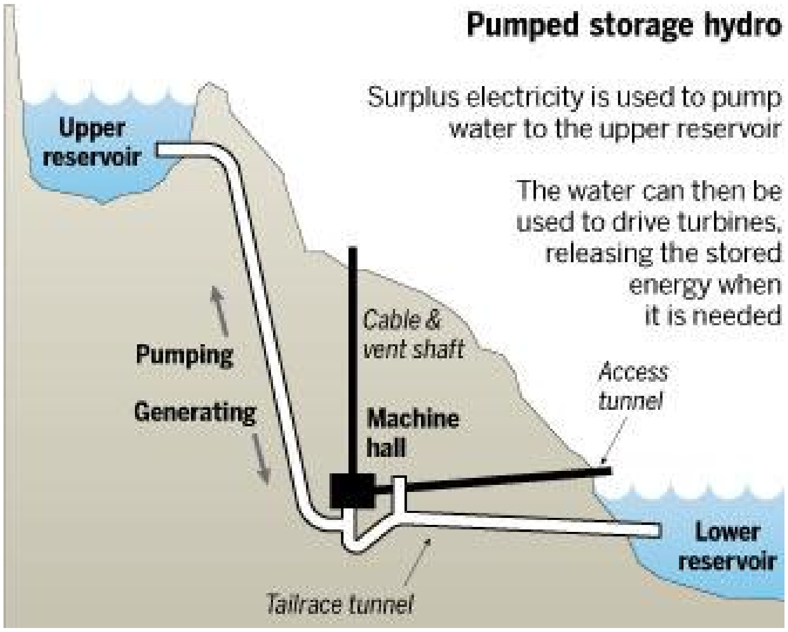


Fig. 13. Pumped Storage Hydro (Financial Times, 2015).

Future storage possibilities for pumped hydro storage in proximity to Louisville include the Taylorsville Lake Dam which has been identified as possible site for a 16.9 MW hydroelectric generator (Kinloch, 2010). There are possibly other suitable sites in the state for similar facilities considering that the Kentucky Department for Natural

Resources (2008) reports 30,000 abandoned mines in the state. The addition of pumped-storage infrastructure at Taylorsville Lake and more abandoned mines could provide electricity generation and storage for the city of Louisville, but more research on this is needed.

Utility Scale Battery Storage

LG&E could also purchase large batteries for storage at power plants, next to their solar arrays, or at other company sites. According to Carnegie, Gotham, Nderitu, & Preckel (2013), utility scale electricity storage can be deployed at any of the five major subsystems in the electric power system: generation, transmission, substations, distribution, and at the point of consumption. Batteries can be used in most, if not all, of these locations. The Sunverge Energy batteries in Glasgow, Kentucky are an example of storage at the final consumer. An example of storage at the site of generation would be General Electric's (n.d.) "Brilliant" PowerUp Platform that combines wind turbines and batteries. Some utilities use flow batteries. Flow batteries use liquid chemicals separated by a membrane akin to a fuel call that allows the battery to be recharged repeatedly (Energy Storage Association, n.d.). The U.S. Department of Energy (2013) notes that flow batteries were "invented by utilities specifically to provide MW-scale storage capacity" (p.18). While there are installations as large as 5MW overseas, the largest flow battery storage system reported by the United States Department of Energy (2013) is 600 kW. Other types of battery systems are much larger. When Golden Valley Electrical Association installed a 40 MW Ni-Cd battery in 2003, it was touted as the "world's largest battery" and is reported to provide electricity for 12,000 people for seven minutes

(Conway, 2003). Tesla (n.d.b.) markets utility-scale batteries in 100kWh blocks that can be grouped to produce “from 500kWh to 10MWh+.” The only source for a cost estimate on this battery is found on the Tesla CEO Elon Musk’s Twitter page of $250 per kWh (Musk, 2015).

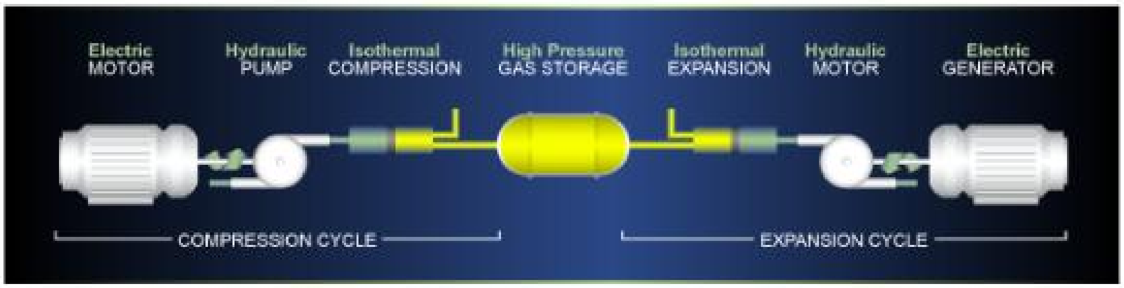


Fig. 14. Isothermal compression diagram (Agrawal et al., 2011).

Compressed Air Energy Storage (CAES)

CAES is where air is pumped into a chamber under pressure by a compressor to be stored until needed then released to be converted back to electricity. Some forms of CAES (diabatic and adiabatic) use fossil fuels to heat the air during the reconversion process; these are not being considered for a 100%-renewable-energy paradigm (Carnegie et al., 2013). A third form of CAES, call isothermal compressed air energy storage (Figure 14), does not involve fossil fuels (Carnegie et al., 2013). CAES can use geological formations (e.g. salt caverns, excavated coal mines, or aquifers) or human made containers (e.g. pipes, transportable vessels, or underwater bladders) to contain the compressed air (Carnegie et al., 2013; Agrawal et al., 2011).

Limiting the use of CAES to isothermal or near isothermal CAES reduces the application to small-scale short-term projects, but they can still be purchased currently from companies such as SustainX and operate at 1MW for 4 hours. Multiple systems could supplement much needed overnight energy storage. Fthenakis, Mason, & Zweibel (2008) concluded that "CAES is a proven technology that is economical for large bulk storage and can provide cycling capability, regulation, and quick start, which are sufficient for both peak and base-load applications" (p. 389). There is a fully-functional 110MW CAES plant in McIntosh, Alabama (Figure 15) owned by PowerSouth Energy Cooperative (n.d.) that uses a salt cavern to store enough electricity to power almost 110,000 homes for up to 26 hours. Compressed air storage that uses pipes, transportable vessels, or underwater bladders is commercially available and could be purchased by LG&E as the need arises.

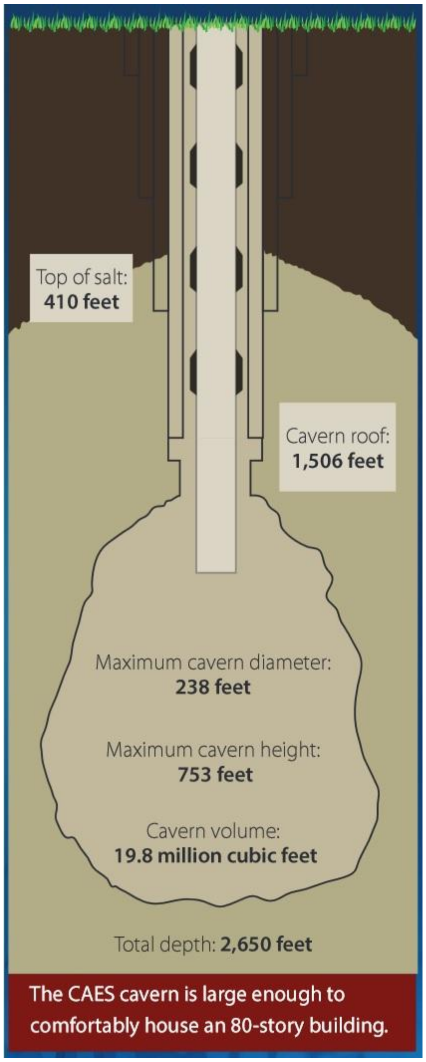


Fig. 15. Schematic of the PowerSouth Energy Cooperative compressed air energy storage facility in McIntosh, Alabama (PowerSource, 2010).

Capacitors and Other Short-term Storage Devices

Super capacitor energy storage, ultra capacitor energy storage, and superconducting magnetic energy storage (SMES) all work well as sources of short-term (less than one hour) storage devices that will help to offset some of the intermittency of wind and solar, but they are not sufficient for long-term (greater than one hour) energy storage (Molina, 2010). Super and ultra capacitors, also known as advanced electrochemical capacitors, use two activated carbon electrodes immersed in an electrolytic solution (such as potassium hydroxide or sulferic acid) (Molina, 2010). The electric current is passed through the electrodes and stores the energy in the micropores of the carbon in the form of an electric field. Because these capacitors do not store energy using a chemical reaction like batteries, the have very little maintanance, an exceptionally long lifespan, do not degrade like batteries, and are more than 95% efficient (Molina, 2010; St. John, 2013). In 2013, the University of California San Diego installed an experimental 2.5 kWh ultracapacitor array that stores electricty produced by a solar array. The system can store 2.5 kW of electricity for about 5 minutes. This helps to smooth the intermittancy of the solar array (St. John, 2013). There are millions of ultracapitors in use around the world and the market for them is growing rapidly (Maxwell Technologies, n.d.). Super and ultra capacitors will be needed by LG&E counteract the intermittancy of solar electicity generation.

Superconducting magnetic energy storage devices can store and discharge "large quantities of power almost instantaneously" according to SuperPower, Inc. (n.d.), an SMES manufacturer. SMES uses a cryogenically cooled coil of superconducting wire to store the electricity within its magnetic field (Holla, 2015). Certain metals reach a state of superconductivity when they reach various temperatures (Holla, 2015). There are a number of SMES systems in place around the world, including a 20 kW system at the University of Houston able to release 0.6 kWh and a system owned by the Bonneville Power Administration in Tacoma, Washington able to release up to 2.8 kWh of energy (Holla, 2015). These systems can help LG&E to mitigate the short-term intermittency issues associated with the harvesting of solar energy.

Flywheel Energy Storage (FES)

A flywheel is a mechanical device that stores energy in the form of kinetic energy by spinning a rotor on an axis with very little friction (Figure 16). The rotor can spin at high speeds and be used to generate electricity at a moments' notice when needed. Flywheels are an efficient way to store energy (Molina, 2010). Carnegie et al. (2013) found that FES used for power applications ranged between 100 kW to 2 MW and exhibited discharge times of between 5 and 50 seconds. Flywheels have a significantly longer life than batteries and a smaller environmental impact. While mostly for short-term storage, flywheels can also help with long-term storage (e.g. greater than one hour) and can be purchased by Louisville residents or businesses or by LG&E to help smooth the intermittent nature of solar.

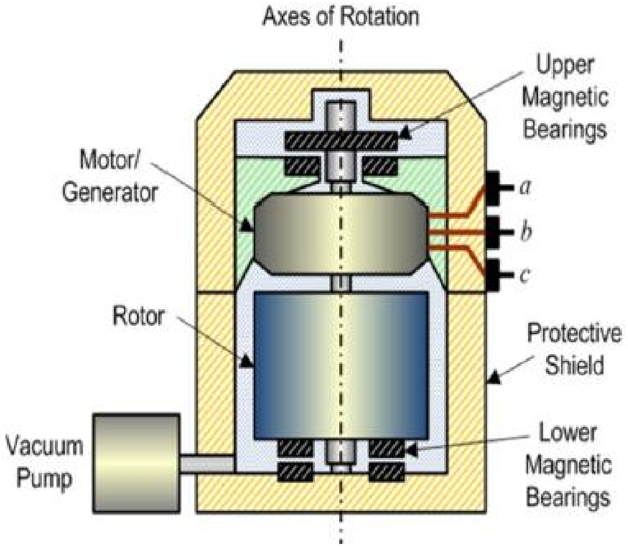


Fig. 16. Flywheel diagram (Molina, 2010, p. 55).

Nelder (2013) reports that flywheels on the household scale can be charged fully within five hours and store 15 kWh of energy, enough to run a modest house through the night, and multiple units can be linked together to store even more. The company Velkess (n.d.) has announced that it is taking orders for their 15kWh Velkess L flywheels that it plans to start delivering in 2016. On the utility scale, Beacon Power operates two 20 MW facilities in Hazle, Pennsylvania that each contain 200 flywheels (Fairley, 2014). The flywheel industry is expected to grow at a rate of 21% from 2013 to 2018 (PR Newswire, 2014). A comparison of the various storage methods (Figure 17) shows their relation to each other in terms of how long they can store energy. The short-term storage is helpful for dealing with intermittency that occurs for less than one hour such as brief stoppage of wind or a cloud that moves over a solar panel. The long-term storage is better for addressing the issues such as cloudy days or the setting of the sun when wind is not blowing.

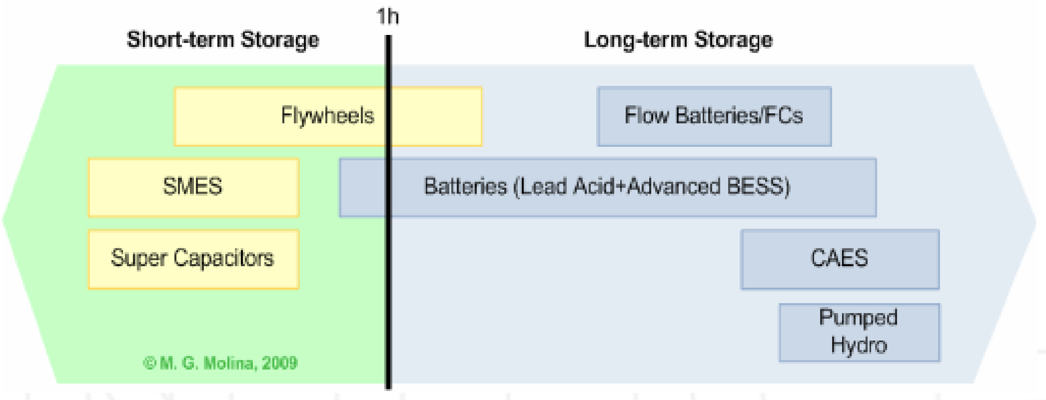


Fig. 17. Comparison of storage devices (Molina, 2010, p. 51).

Other Strategies

Smart Grid

In order to handle issues like the surge in load demand due to charging of EVs and the intermittent nature of renewable energy, LG&E will need to include more smart grid technology. This computer-based remote control technology allows users and producers of electricity to anticipate, and even control, the flow of energy through increased levels of communication (U.S. Department of Energy, n.d.). Smart grid technology includes, among other things, the ability for electricity to flow in both directions, like when a section of the grid produces excess electricity from solar or wind while another section is consuming more power. A smart grid can also include smart meters that communicate with the utility so that human meter readers are not needed, therefore reducing costs. LG&E already uses smart grid technology with their demand conservation and Advance Meter Service programs. Smart meters can also accommodate time-of-day pricing that charges higher rates during peak periods and lower rates off peak. This will incentivize users to lower their usage during periods of high costs thus helping utilities to reduce the peak in demand. LG&E already has the ability to reduce the load by temporarily turning off major appliances like air conditioners (U. S. Department of Energy, n.d.). This ability is needed during periods of high demand so that the company can avoid buying electricity from other locations and to possibly avoid brownouts and blackouts. As mentioned previously, electric vehicle chargers that are connected to vehicles can be remotely turned on to pull excess energy from the grid during times of surplus generation and store it in vehicles, then reverse the flow when demand is high. Once all of the vehicles in Louisville have been replaced with electric vehicles, they will have the potential to store 19.5 GWh of electricity. This can reduce the need for energy curtailment. Pricing models would give EV owners the incentive to have vehicles plugged in and ready to charge during the sunniest parts of the day and use the EVs as grid energy storage at other times of day. This would also provide an incentive for utilities and business owners to install charging stations near workplaces (Silver Spring Networks, 2013). LG&E would benefit by having access to electricity storage without the burden of having to purchase it and the business owners could be rewarded by the utilities through the rate structure for providing this employee benefit.

Smart inverters are being tested in parts of the country that are already seeing higher levels of solar penetration (Trabish, 2014). These devices are controlled by the utility and help regulate the voltage that feeds back onto the grid. Smart inverters can help mitigate bidirectional flow issues and prevent potential damage to distribution and transmission system equipment (Trabish, 2014).

LG&E offers many services through their Demand Side Management (DSM) program that can help to reduce energy use in homes and businesses. They initiated an Advanced Meter Service program that provides smart meters to 5,000 customers that will help them monitor their energy use and measure savings when changes are made (LG&E, n.d.).

Demand Response

Demand response is another demand-side strategy that can be used to mitigate the variability of solar. Demand response includes a myriad of strategies that are aimed at incentivizing a reduction in energy use for consumers during times of high demand. Demand response includes time-of-day pricing and direct load control programs. In order to change people's behavior with regards to electricity use, there has been much success with using time-of-day, or time-of-use, pricing with industrial customers where users are charged more during high-demand periods of the day and less during the low-demand hours. The company also provides reduced rates to some of their larger customers in exchange for the right to curtail delivery of electricity to that customer on short notice. These curtailable rider tariffs allow the utility to greatly reduce demand when needed and avoid the costs associated with meeting peaks in demand (Kentucky Public Service Commission, 2012). This tactic helps to "shave the peak," or reduce energy consumption during the times of the day when demand peaks. This can reduce the utility's expenditures for electricity purchases from other utilities. Time-of-day pricing can be implemented through the installation of a "smart" meter that can measure the usage at various times of the day and provides a financial incentive for the customers to change their usage patterns. Consumers could use timers on their dishwashers, clothes washers, dryers, or other large appliances to come on during periods of low demand (and low price). Once there is significant penetration of solar energy onto the grid, time-of-day pricing will encourage users to conserve at night when the sun is not shining and solar production is low. Additionally, this will incentivize the use of batteries that can be programmed to charge during the low priced periods and discharge during the high-priced periods. Time-of-day pricing will also encourage people to charge their car batteries during the day and not at night. This should significantly help mitigate ramping issues in the evening (Lazar, 2014).

Another strategy for addressing the intermittency of renewable energy includes strategies that give the utility the ability to take control of and power down some of the customer's appliances when needed. This is referred to as direct load control or supply side interruptible load. LG&E already has a program that cycles off air conditioners in homes and businesses. This is implemented on a rolling basis to avoid impacting the comfort of the homeowner, but still achieving an overall reduction in demand when needed. The U.S. Department of Energy's Energy Information Administration (EIA) (2002) reported that in 2000 (the last year for which this study was conveyed) 962 utilities had implemented demand-side management programs that were able to save 53.7 billion kWh of electricity and reduce the peak load by 22,901 MW. Mai, et al. (2014) estimate that in a 90% renewable energy scenario, that approximately 35% of the operating reserves would come from supply side interruptible load. Another supply side interruptible load strategy involves thermal storage air conditioners. Thermal storage air conditioners are the latest technology in central air conditioning units and large building cooling systems. These units have the ability to store energy in the form of chilled water or ice that can be used later to produce the cool air for the building. This allows the utility to employ these units in order to store energy during periods of peak solar production and would help to smooth the demand curve (Lazar, 2014). It is theoretically possible to store energy in the form of heat, but there are no commercially available systems of that type currently available to the average commercial consumer. Another supply side interruptible load strategy is directed at one particular type of consumer, aluminum smelters, a large industry in Kentucky. According to the U. S. Department of Energy (February 2007), the aluminum production industry is the largest consumer of energy on a per-weight basis and also the largest electricity consumer of all manufactured products. As another example of direct load control, Milligan et al. (2012) say it is possible that an aluminum smelter could be designed to operate under increased flexibility so as to make use of excess nightly wind power. This would help alleviate minimum load problems in Kentucky and LG&E could provide lower electricity rates for the smelters as an incentive.

Mitigating Curtailment

Surplus energy has to be curtailed to avoid an excessive imbalance between supply and demand. High levels of curtailment may be necessary on sunny days. Mai, et al., (2012a) conclude that a variety of technical approaches could be implemented to reduce these levels of curtailment. They recommend the construction of additional transmission capacity in parts of the grid that are congested. This would allow more electricity to be transmitted to other regions and can help to balance surpluses of wind and solar generated within Kentucky. Mai, et al., (2012a) also observe that increasing the size of reserve-sharing groups could help. LG&E can enter into cooperative agreements to meet their required operating reserves so that they can share reserve capacity when needed (NERC, 2015). These reserve-sharing groups, according to Mai, et al. (2012a), would reduce the total number of inflexible generators online and curtailment could be reduced if fewer plants operate only at minimum levels. Storage of electricity during times of surplus will also help to mitigate curtailment. Storage is discussed in greater detail below. When a significant amount of solar energy is incorporated into the grid, a larger operating reserve would be necessary to address fluctuations. According to Mai, et al. (2014), additional operating reserves were needed in high variable renewable generation systems modeling and they found these reserves through the availability of conventional power plants, storage technologies, and demand-side practices. In a 100% renewable scenario, conventional fossil fuel plants would be eliminated and replaced with biomass generation, additional storage, greater sharing of surplus energy on a regional basis, and demand-side strategies.

Flattening the Duck Curve

Chapter I includes a discussion about the “Duck Curve” that helps to illustrate the ramping issues created by the timing of the peak morning and evening demands that fall outside of the increase in solar energy production. Lazar (2014) gives strategies to help flatten the “duck curve” and mitigate the ramping issues. These may help LG&E and the city once solar penetration approaches 50%. For instance, he recommends orienting solar panels to the west instead of the traditional direction of south to increase evening production at the expense of morning production (Lazar, 2014). Time of day pricing could be the incentive to get homeowners to reorient their panels because production during the late afternoon peak would save more money per hour (Lazar, 2014). Ramping issues will disappear when the last fossil fuel combustion generators are retired. Ramping will be replaced by discharging of energy from storage and from the combustion of bioenergy.

Recommendations

A full scale conversion of a city's transportation fleet and its energy production infrastructure is an immense undertaking that would need to involve many of the stakeholders of the community. These recommendations are divided into the three sectors of government, business, and non-profit. Participation from all of these groups is needed to facilitate a transition of this magnitude.

Government Sector

City officials and business leaders can take steps to help bring about the transformation of Louisville's electricity and transportation systems. Government investment in infrastructure (delineated below) is needed to incentivize businesses to hire employees and will provide the related industries with the revenues they need to grow. The logical first step is the installation of solar photovoltaic panels and EV charging stations at city-owned properties including Jefferson County Public Schools and TARC buildings. This will save the local government on fuel and utilities in the long run thus reducing operating costs. Special charging infrastructure is not crucial to replacing the fleet with electric vehicles since EVs can be charged using household electrical outlets, but additional superchargers will help to convince drivers to make the move to all-electric vehicles. The city can partner with businesses and provide incentives to encourage the installation of these stations throughout the city. TARC should continue to purchase electric buses and expand their reach throughout the city. Additional public transportation options like bus rapid transit (BRT) and light-rail should be implemented without delay. There are a number of policies that the Louisville Metro Council and the

Kentucky General Assembly can consider to incentivize these changes. See Policy Issues below for details.

Business Sector

The loss of jobs is often cited as a concern when there are discussions of changing to a more renewable energy paradigm. This is understandable if that new energy paradigm includes importing energy from other parts of the country or the world. That is why it is important to take the steps needed to retool the community's manufacturing processes to produce electric cars, photovoltaic panels and wind turbines in the state. It is also important to implement the conservation and efficiency needed to keep utility rates low in order to continue to draw energy-intensive manufacturing jobs to the state. For example, in 2014, Kentucky had the most aluminum smelters of any state in the U.S., employing 20,000 workers in the state (Serchuk, 2014). While some of these have since closed due to foreign competition, this industry is still a major employer in the state, is tied to the auto industry, and is drawn to the state's low electricity rates. The automotive industry at the end of this cheap-electricity supply chain is the second highest export industry in the state (Serchuk, 2014). Louisville has two auto manufacturing plants, a cold rolled aluminum supplier, and numerous auto parts manufacturers (Serchuk, 2014). Keeping those jobs in the area is important to the economic vitality of the region as the transition to renewable sources progresses.

During the transition to an all-electric all-renewable future more jobs can be created in the renewable energy and energy efficiency fields than are lost in the fossil fuel industry (Hornby, at al., 2012). According to the Kentucky Energy and Environment

Cabinet (2016), coal mining jobs in Kentucky declined by 27.7% in 2015. This trend is expected to continue as natural gas prices stay low and more emphasis is placed on reducing carbon dioxide emissions. The creation of renewable energy and energy efficiency jobs can reverse that trend. Conservation and efficiency can not only help to keep energy bills low, but can create jobs for energy auditors and engineers, and those who install windows, doors, insulation, heat pumps, efficient lighting, awnings, ceiling fans, and other energy saving devices. Hornby, et al. (2012) estimate that an increase in renewable energy of up to 12.5% and an increase in energy efficiency of up to 10.25% would bring $1.5 billion in revenue to the state economy and create more than 28,000 job years.

Other job creation opportunities include: manufacturing solar panels and EnergyStar appliances at General Electric's Appliance Park; retooling one of the Ford plants to assemble the Ford Focus Electric vehicle; increased production of Tedlar (the plastic coating used in making solar PV panels) at the Louisville DuPont plant; construction and operation of biodigesters of sewage and other organic wastes; and solar installation jobs. LG&E will need to hire experts on solar, wind, and storage technology and hire more people to work on demand side management (DSM) and smart grid programs. If city officials make a commitment to a conversion of the grid to renewable sources and the purchasing of electric vehicles, this will draw new employers in the form of auto manufacturers, solar manufacturers and installers, and energy conservation and efficiency enterprises.

According to the local chamber of commerce, Greater Louisville, Inc. (n.d.), LG&E currently employs almost 2,200 people. Louisville Gas & Electric can implement programs to accelerate the transition to an all-electric all-renewable future. Freeman and Parks (2016) note that utilities need to be more service oriented and focus on distribution, transmission, and efficiency more than generation. Expansion of the company's demand side management (DSM) program and implementation of more smart-grid technologies will help reduce demand and provide the utility with the tools needed to address intermittency. An aggressive program of solar installations across the city can be accomplished by providing business customers with installation services and panels and rewarding them by guaranteeing a fixed rate for electricity consumption for a predetermined number of years. Additionally, the utility needs to install solar arrays on all of their existing properties and look for suitable sites across the city for additional installations. Panels should be installed on rights of way, such as the area adjacent to expressways and in clover leafs, parking lots, and parking garages wherever practical. Contracts with companies that can provide locally generated biogas should be pursued immediately. LG&E can progressively increase the amount of natural gas from renewable sources by tapping more sources of biogas. Eventually, LG&E can entirely eliminate its use of fossil-fuel derived natural gas.

The utility can also encourage more customers to heat with ground source and air source heat pumps that are more efficient ways to heat homes and businesses and do not use natural gas. A drastic expansion in the company's DSM program would facilitate much larger reductions in energy use by facilitating the installation of insulation, insulated windows and doors, programmable thermostats, efficient lighting, and efficient EnergyStar appliances.

Encouraging customers to buy electric cars can be a great opportunity for LG&E to grow their business (Freeman & Parks, 2016). Installing free public charging stations would eventually pay for themselves as the increase in customers with electric cars would generate revenues for the utility when they also charge the vehicles at home or other private charging stations. LG&E can also implement a program where it purchases the batteries in customers EV's similar to the program implemented by LADWP in Los Angeles to provide storage for the utility and make the purchase of EV's more affordable to the customers (Freeman & Parks, 2016).

Non-profit Sector

Non-profits also play a role in forming the future of the community in Louisville through education and advocacy on energy efficiency and alternative energy. There are many organizations that should be supported and encouraged in their work to help the community transition to a renewable energy future. Project Warm, a Louisville-based non-profit, provides weatherization and other energy reduction services to low-income residents. The Coalition for the Advancement of Regional Transportation is an advocacy group that has promoted multi-modal transportation in the city since 1992. The Louisville Sustainability Council uses the collective impact model to engage business leaders, non-profits and government to work together to achieve gains in sustainability within the community (in the interest of full disclosure, the author of this study is currently on the board of directors of this organization). Since 2004, Bicycling for Louisville has worked to make the city safer for bicycles. The Louisville Climate Action Network is working to develop its Center for Cutting Carbon and Costs (C4) that will help renters, homeowners, and businesses to reduce their dependence on fossil-fuels (in the interest of full disclosure, the author of this study is currently on the board of directors of this organization). Kentucky Interfaith Power & Light advises houses of worship on conservation, efficiency, and alternative energy (in the interest of full disclosure, the author of this study is currently the executive director of this organization). The Kentucky Chapter of the US Green Building Council promotes LEED (Leadership in Energy & Environmental Design) standards for buildings in the city. 350 Louisville, Kentuckians for the Commonwealth and the Greater Louisville Sierra Club have advocated for sustainability options for the city for many years. EVolve is an organization of electric car owners working to promote EV ownership. The Kentucky Solar Energy Society is an organization of local solar installers and other solar advocates. The University of Louisville Conn Center for Renewable Energy Research has been conducting research on solar energy and other renewable energy technologies since 2009 (Conn Center, n.d.). The Louisville Energy Alliance uses educational events and programs to educate commercial building owners and managers helping them access resources to improve energy efficiency, reduce energy consumption, and obtain Energy Star certification. Habitat for Humanity constructed energy efficient homes and installed solar panels in other cities around the country (Habitat for Humanity, 2014, Constellation, n.d.). With the help of solar installers, LG&E and perhaps a solar manufacturer, Habitat for Humanity of Metro Louisville could do something similar locally. Governments and individuals should continue to support these organizations in their work by participating in their programs, helping them to find funding, and helping them find volunteers.

Policy Issues

There are a number of policy issues on the state and local level that could help to facilitate the transition to a 100% renewable energy electric grid and an all-electric vehicle fleet.

Portfolio standards. A portfolio standard is a regulatory tool that utilities must adhere to which dictates the sources used to generate electricity and the level of efficiency that is used. There are two main types of portfolio standards, renewable energy portfolio standards (REPS) and energy efficiency standards (EES). An REPS is a regulatory mandate that requires utilities to increase their production renewable of energy to specific percentages by specific dates (NREL, 2015b). Twenty-nine states and even some municipalities have passed laws mandating these standards. Los Angeles, California has a REPS mandate of 33% renewable energy by 2020 and 50% by 2030 (Freeman and Parks, 2016). The Kentucky Sustainable Energy Alliance (n.d.) has, since 2010, initiated bills in the Kentucky General Assembly that call for a 10.25% by 2022 EES and a REPS mandate of 12.5% by 2022. An EES requires a utility to increase the efficiency at which their electricity is used. This can be accomplished in many ways, but usually involves providing customers with help in implementing efficient lighting, HVAC, programmable thermostats and other measures through rebates and free products. Former Kentucky Governor Steve Beshear developed a REPS energy plan "whereby 25 percent of Kentucky's energy needs in 2025 will be met by reductions through energy efficiency and conservation and through the use of renewable resources" (Beshear, 2008, p. iv). Hornby, at al. (2012) indicate that an EES mandate of 10.25% and a 12.5% REPS would create over 28,000 net additional jobs and would keep utility costs lower while also increasing the state's renewable electricity production.

Feed-in tariff. A feed-in tariff (FIT) is where local utilities pay for customer-generated solar or wind energy (Freeman & Parks, 2016). The city of Los Angeles Department of Water and Power (LADWP) has a feed-in tariff that is expected to pay customers who install solar panels for their solar-generated electricity for up to 150MW of installed capacity by 2020 (Freeman & Parks, 2016). The Tennessee Valley Authority (TVA), a utility that provides electricity to many parts of Kentucky, implemented a Green Providers Program in 2012 that offers 12 cents per kWh through a FIT (TVA, n.d.; Williams, 2012). Kentucky Sustainable Energy Alliance (n.d.) has initiated bills in the Kentucky General Assembly that call for a FIT. A FIT would reduce the payback period for solar and could be a boon to solar development as it was in Europe and Japan (Project Finance, 2014).

Building codes. Building codes can be changed to require that new buildings meet energy efficiency standards and in reducing energy use, reduce the cost of operating a business or using household energy. Additionally, new developments could be required to include a mix of smaller affordable homes that would reverse the trend toward larger more energy hungry homes.

Financing mechanisms. The Kentucky General Assembly passed the Energy Performance Assessment District (EPAD) legislation in March 2015. This allows businesses and non-profits to finance their energy efficiency and alternative energy projects with loans that are repaid through their property tax bills (Lane Report, 2015). This type of financing makes energy efficiency and alternative energy projects more affordable. The Louisville Metro Council is expected to consider the local ordinance that will allow EPAD for Metro Louisville in March 2016 (personal communication, Bill Hollander, 2016). An expansion of this state law, and the corresponding local ordinance, should be adopted to make this financing option available to residual properties.

Net-metering expansion. In April 2008, the Kentucky General Assembly passed a law that requires utilities to allow customers to install renewable energy without the need for batteries by tying their systems to the grid so that the electricity flows backwards under a net metering agreement, however this does not cover systems greater than 30 kW of capacity (DSIRE, 2015). An expansion of the net metering law would provide an incentive for businesses to make larger investments in solar, biomass, and wind. Sen. Morgan McGarvey sponsored such a bill in the 2015 session of the General Assembly (Legiscan, 2015) and is expected to reintroduce a similar bill in 2017.

Land use regulations. Anti-sprawl legislation should be implemented to halt or slow suburban development and incentives for in-fill development should be introduced. A more compact city will increase transportation efficiency and, in turn, enhance the use of public transportation and cycling. Transit-oriented development is needed to reverse the auto-centric development that makes alternative transportation modes more difficult to use. Complete Streets design that "integrates people and place in the planning, design, construction, operation, and maintenance of transportation networks" should be put into practice along all major thoroughfares to increase pedestrian and bicycle safety and encourage a shift on mode share (Smart Growth America, n.d.).

Conclusion

While still monumental in cost and scope, it is possible to achieve a conversion of the Louisville electrical grid to 100%-renewably-sourced electricity and replacement of the vehicles with electric engine vehicles by 2050. Conservation and efficiency measures are needed to reduce the demand for energy to a more manageable and affordable level. Expansion of the use of renewable energy sources other than solar is necessary to meet nighttime base load demand and provide the dispatchability needed for grid stability. Storage capacity will need to be added to address intermittency and supplement the base load demand. A transformation of this magnitude will require a large commitment from the community and full participation of the governmental, business, and non-profit sectors.

Some changes can take place immediately. Conservation and efficiency improvements can be implemented without delay. City government should invest heavily in energy efficiency because the improvements will pay for themselves and reduce the cost of operating buildings. Those savings can fund improvements in public transportation and reduce fares to encourage mode shift. Generous tax breaks for businesses that manufacture renewable energy equipment and components such as solar panels, biodigesters, and wind turbines and businesses that manufacture electric cars and parts, will create jobs and increase tax revenues. The city can mandate that all city-owned vehicles, including TARC buses and school buses be electric saving the city, TARC, and Jefferson County Public Schools due to lower fuel costs.

Tax breaks for businesses that purchase electric vehicles and energy efficiency upgrades can accompany taxes on fossil fuels. City-based renewable portfolio standards will allow LG&E to start constructing large solar arrays around the city and encourage hydroelectric, biomass energy, and wind power development in the region. Development of these industries will help to reverse the loss of coal jobs in the state. LG&E can be at the forefront of this national movement by defining the role of utilities of the future and embracing the technologies like smart grid, storage, and V2G that are revolutionizing the industry.

Local government can provide grants to non-profits that promote energy efficiency, alternative energy, and electric vehicles. The non-profits can help low-income households to reduce their energy costs and avoid large spikes during the transition. These non-profits can educate businesses and residents about the importance and implementation of energy efficiency and conservation.

Louisville can be a model for other cities that are also facing the daunting task of transitioning away from a heavy dependence on fossil fuels.

References

Agrawal, P., Nourai, A., Markel, L., Fioravanti, R., Gordon, P., Tong, N., & Huff, G. (2011). Characterization and Assessment of Novel Bulk Storage Technologies, Sandia National Laboratories.

American Chemical Society (2013). Understanding the life of lithium ion batteries in electric vehicles. Retrieved from http://www.acs.org/content/acs/en/pressroom/newsreleases/2013/april/understanding-the-life-of-lithium-ion-batteries-in-electric-vehicles.html.

Anderson, K., Bomford, M., Cagle, J., Holmes, K., Montross, M., Moore, F., Shanks, K., Stringer, J., Taylor, E., Thomas, B. (2009). Final Report from the Executive Task Force on Biomass and Biofuels Development in Kentucky.

Augustine, C.; Bain, R.; Chapman, J.; Denholm, P.; Drury, E.; Hall, D.G.; Lantz, E.; Margolis, R.; Thresher, R.; Sandor, D.; Bishop, N.A.; Brown, S.R.; Cada, G.F.; Felker, F.; Fernandez, S.J.; Goodrich, A.C.; Hagerman, G.; Heath, G.; O'Neil, S.; Paquette, J.; Tegen, S.; Young, K. (2012). Renewable Electricity Generation and Storage Technologies. Vol 2. of Renewable Electricity Futures Study. NREL/TP-6A20-52409-2. Golden, CO: National Renewable Energy Laboratory.

Austin, A. (2012). Revitalizing Rubbertown. *Biomass Magazine*. January 25, 2012. Retrieved from http://biomassmagazine.com/articles/6120/revitalizing-rubbertown/.

Bailey, B., Hansen, E., Groschner, H., McIlmoil, R., Hartz, L., Shaver, J., & Hereford, A. (2012). A Windfall for Coal Country? Exploring the Barriers to Wind Development in Appalachia.

BatteryUniversity.com (n.d.). Retrieved from http://batteryuniversity.com/_img/content/secondary_chart.jpg.

Bellarmine University (2009). Clean-up Complete and Drilling Resumed for Geothermal Field. Retrieved from http://www.bellarmine.edu/news/news-item/2009/11/25/clean-up-complete-and-drilling-resumed-for-geothermal-field/

Beshear, S. (2008). Kentucky Department for Energy Development and Independence. Intelligent Energy Choices for Kentucky's Future: Kentucky's 7-Point Strategy for Energy Independence.

Bowling, C. (2015). Indiana company still at odds with west Louisville residents over methane plant. *Insider Louisville,* September 25, 2015.

Bradshaw, A. M., Reuter, B., & Hamacher, T. (2015). Could the extensive use of rare elements in renewable energy technologies become cause for concern? EPJ Web of Conferences 98, 04007 (2015). DOI: 10.1051/epjconf/20159804007.

Bronski, P., Creyts, J., Guccione, L., Madrazo, M., Mandel, J., Rader, B., & Seif, D. (n.d.). The Economics of Grid Defection: When and where distributed solar generation plus storage competes with traditional utility service. Rocky Mountain Institute. Retrieved February 27, 2016 from http://www.rmi.org/electricity_grid_defection.

Brookings Institute (2005). Blueprint for American Prosperity: Vehicle Miles Traveled. Retrieved from http://www.brookings.edu/~/media/Research/Files/Reports/2008/6/metropolicy/vehicle_miles_traveld.PDF.

Boundy, B., Diegel, S. W., Wright, L., Davis, S. C. (2011). Oak Ridge National Laboratory. Biomass Energy Data Book: Edition 4. Retrieved from http://cta.ornl.gov/bedb/download.shtml.

Brown, M. A., Southworth, F., Stovall, T. K. (2005). Towards a climate-friendly built environment. Pew Center on Global Climate Change. Retrieved from http://www.c2es.org/docUploads/Buildings_FINAL.pdf.

Bruggers, J. (2014a). Climate change warming Kentucky, Indiana report says. *The Courier-Journal,* May 7, 2014. Retrieved from http://www.courier-journal.com/story/tech/science/environment/2014/05/06/national-climate-assessment-southeast-region/8765423/.

Bruggers, J. (2014b). MSD fertilizer losing money as rates rise. *The Courier-Journal*, December 2, 2014.

Bruggers, J. (2015a). Going Solar. *The Courier-Journal*, September 1, 2015.

Bruggers, J. (2015b). Nature's Methane offers $5M to West End leaders. *The Courier-Journal*, November 4, 2015.

Bruggers, J. (2015c). Sixty years of coal burning ends at LG&E plant. *The Courier-Journal*, July 7, 2015.

Budischak, C., Sewell, D., Thomson, H., Mach, L., Veron, D., & Kempton, W. (2012). Cost-minimized combinations of wind power, solar power and electrochemical storage, powering the grid up to 99.9% of the time. *Journal of Power Sources* 225(2013) 60-74.

California Energy Commission (n.d.). Energy Almanac: U.S. per capita electricity use by state in 2010. Retrieved from http://energyalmanac.ca.gov/electricity/us_per_capita_electricity-2010.html.

California Energy Commission (n.d.). Alta wind farm powers homes. Retrieved from http://www.energy.ca.gov/tour/alta/.

Callaway & Hiskens (2011). Achieving controllability of electric loads. *Proceedings of the IEEE* 99(1) 184-199.

Carnegie, R., Gotham, D., Nderitu, D., & Preckel, P. (2013). Utility Scale Energy Storage Systems: Benefits, applications, and technologies. Retrieved from http://www.purdue.edu/discoverypark/energy/assets/pdfs/SUFG/publications/SUFG%20Energy%20Storage%20Report.pdf.

Census Transportation Planning Products (n.d.). Means of Transportation (18) (Workers 16 years and over). U.S. Census Bureau, American Community Survey 2006-2010 Five-year estimates. Special Tabulation: Census Transportation Planning. Retrieved from http://data5.ctpp.transportation.org/ctpp/View/dispview.aspx.

Chan, C., Jian, L. & Tu, D. (2014). Smart charging of electric vehicles – integration of energy and information. *IET Electrical Systems in Transportation* December 2014. DOI: 10.1049/iet-est.2013.0025.

Chaves, A. & Bahill, A. T. (2010). Locating sites for photovoltaic solar panels: Pilot study uses DEM derived from LiDAR. *ArcUser.* Fall 2010, p. 24-27.

City of Louisville (2013). Louisville to supply wood waste to Recast Energy. *Biomass Magazine*, February 20, 2013. Retrieved from http://biomassmagazine.com/articles/8650/louisville-to-supply-wood-waste-to-recast-energy.

Clark, K. (2015). Norton Commons to drill for geothermal energy. *The Courier-Journal,* February 2, 2015.

Clauser, G. (2015). 4 Smart Energy Systems to Help You Control Your Electricity Bill. Electronic House Network. Retrieved from http://www.electronichouse.com/daily/home-energy-management/4-smart-energy-management-systems-help-control-electricity-bill/.

Constellation (n.d.). Habitat for Humanity. Retrieved February 13, 2016 from http://www.constellation.com/community/pages/habitat-for-humanity.aspx.

Colliver, D., Bush, J., Davis, A., Montrass, M., Fehr, R., Gates, R., Halich, G., & Nokes, S. (2008). Kentucky Resources to Meet the Energy Needs of the 25 x ’25 Initiative.

Conn Center (n.d.). Welcome to the Conn Center for Renewable Energy Research. Retrieved February 14, 2016 from http://conncenter.org/.

Conway, E. (2003). World’s biggest battery switched on in Alaska. *The Telegraph.* Retrieved from http://www.telegraph.co.uk/technology/3312118/Worlds-biggest-battery-switched-on-in-Alaska.html.

Courier-Journal (2016). Sullivan ‘Supercharge’ promotes electric cars. *The Courier-Journal.*

Cuellar, A. D. & Webber, M. E. (2008). Cow power: the energy and emissions benefits of converting manure to biogas. *Environmental Research Letters* (3) 3. DOI: 10/1088/1748-9326/3/3/034002.

Darby, S. (2006). The effectiveness of feedback on energy consumption. Retrieved from http://www.eci.ox.ac.uk/research/energy/downloads/smart-metering-report.pdf.

Delmas, M., Kahn, M., & Locke, S. (2014). Accidental Environmentalists? Californian Demand for Teslas and Solar Panels. DOI: 10.3386/w20754.

Delucchi, M. A. & Jacobson, M. Z. (2011). Providing all global energy with wind, water, and solar power, Part II: Reliability, system and transmission costs, and policies. *Energy Policy* 39 (3) 1170–1190. DOI: 10.1016/j.enpol.2010.11.045.

Deutch, J. & Moniz, E. (2010). Electrification of the Transportation System: An MIT Energy Initiative Symposium. Retrieved from http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.464.3955&rep=rep1&type=pdf.

Downs, A., Chittum, A., Hayes, S., Neubauer, M., Nowak, S., Vaidyanathan, S., Farley, K., & Cui, C. (2013). The 2013 State Energy Efficiency Scorecard. American Council for and Energy –Efficient Economy.

DSIRE, Database of State Incentives for Renewables & Efficiency (2015). Net Metering. Retrieved from http://programs.dsireusa.org/system/program/detail/1081.

Ehrhardt-Martinez, K., Donnelly, K., & Laitner, J. (2010). Advanced Metering Initiatives and Residential Feedback Programs: A Meta-Review for Household Electricity-Saving Opportunities. American Council for an Energy-Efficient Economy. Retrieved from http://www.energycollection.us/Energy-Metering/Advanced-Metering-Initiatives.pdf.

EPRI, Electric Power Research Institute (2014). Power-to-Gas (P2G): Generating Hydrogen Fuel and Using Natural Gas Infrastructure for Energy Storage.

EPRI, Electric Power Research Institute (2007). Nationwide Greenhouse Gas Emissions, *Environmental Assessment of Plug-In Hybrid Electric Vehicles.* 1015325. Palo Alto, CA: EPRI. http://mydocs.epri.com/docs/CorporateDocuments/SectorPages/Portfolio/PDM/PHEV-ExecSum-vol1.pdf.

EPRI, Electric Power Research Institute (2009). Assessment of Achievable Potential from Energy Efficiency and Demand Response Programs in the U.S. (2010 – 2030): Executive Summary. Palo Alto, CA.

Encyclopedia of Earth (2008). Silicon.

Energy Vortex (n.d.). Energy Dictionary. Retrieved September 29, 2015 from https://www.energyvortex.com/energydictionary/firm_capacity__firm_energy__nonfirm_energy__firm_power.html.

ESA, Energy Storage Association (n.d.). Hydrogen Energy Storage. Retrieved September 6, 2015 from http://energystorage.org/energy-storage/technologies/hydrogen-energy-storage.

ESA, Energy Storage Association (n.d.). Flow Batteries. Retrieved from http://energystorage.org/energy-storage/storage-technology-comparisons/flow-batteries.

ESRL, Earth System Research Laboratory, National Oceanic and Atmospheric Administration (n.d.). Research for Renewable Energy Development: ESRL's Role in Wind and Solar Development. Retrieved October 4, 2015 from http://www.esrl.noaa.gov/research/renewable_energy/.

Estep, Bill (2015). Hydroelectric power could grow in Kentucky with interest in renewable energy. *Herald-Leader*, December 30, 2015.

Estes, S. S. (2015). STAR Energy pledges 85% of organic waste to come from local sources. Retrieved from http://sehllc.com/news/.

Fairley, P. (2014). Flywheels Get Their Spin Back With Beacon Power's Rebound. IEEE Spectrum. Retrieved from http://spectrum.ieee.org/energy/fossil-fuels/flywheels-get-their-spin-back-with-beacon-powers-rebound.

FERC, Federal Energy Regulatory Commission (2014). Pumped Storage Projects. Retrieved from http://www.ferc.gov/industries/hydropower/gen-info/licensing/pump-storage.asp.

Financial Times (2013). Pumped storage hydro. Retrieved August 23, 2015 from http://www.ft.com/m/html/expandable-picture.htm.

Freeman, S. D. & Parks, L. Y. (2016). All-Electric America: A Climate Solution and the Hopeful Future. Solar Flare Press.

Fthenakis, V., Mason, J. E. & Zweibel, K. (2008). The technical, geographical, and economic feasibility for solar energy to supply the energy needs of the US. *Energy Policy* 37(2009) 387-399.

Fuchs, R. (2011). Wind energy surplus threatens Eastern German power grid. European Dialogue. Retrieved from http://www.eurodialogue.eu/Wind-energy-surplus-threatens-eastern-German-power-grid.

General Electric (n.d.). Integrated Storage. Retrieved September 12, 2015 from https://renewables.gepower.com/wind-energy/technology/integrated-storage.html.

GLI: Greater Louisville Inc. (n.d.). The Metro Chamber of Commerce. Major Employers. Retrieved from http://www.greaterlouisville.com/EconomicDevelopment/TheGreaterLouisvilleRegion/Major_Employers/.

Golden, J. S., Carson, J., Kaloush, K. E., & Phelan, P. (2007). A comparative study of the thermal and radiative impacts of photovoltaic canopies on pavement surface temperatures. *Solar Energy* 81(7), p. 872-883. Doi:10.1016/j.solener.2006.11.007.

Granade, H., Creyts, J., Derkach, A., Farese, P., Nyquist, S., & Ostrowski, K. (2009). McKinsey Global Energy and Materials: Unlocking Energy Efficiency in the Global Economy. McKinsey & Company.

Habitat for Humanity (2014). Sustainable, energy-efficient homes that are affordable and safe. *Habitat.* Retrieved from http://www.habitat.org/blog/sustainable-energy-efficient-affordable-safe-homes-225.

Hayes, S., Herndon, G., Barrett, J., Mauer, J., Molina, M., Neubauer, M., Trombley, D., and Ungar, L. (2014). Change is in the Air: How states can harness energy efficiency to strengthen the economy and reduce pollution. American Council for an Energy-Efficient Economy.

Henao, A. Piatkowski, D., Luckey, K. S., Nordback, K., Marshall, W. E. & Krizek, K. J. (2014). Sustainable transportation infrastructure investments and mode share changes: A 20-year background of Boulder, Colorado. *Transport Policy* 37, 64-71. Retrieved from http://kevinjkrizek.org/wp-content/uploads/2012/04/Transport-policy.pdf.

Holla, R. V. (2015). Energy Storage Methods – Superconducting Magnetic Storage – A Review. *Journal of Undergraduate Research* 5, 1 (2015).

Hornby, R., White, D., Vitolo, T., Corrings, T., & Takahashi, K. (2012). Potential impact of a renewable and energy efficiency portfolio standard in Kentucky. Synapse Energy Economics, Inc.

Hostick, D.; Belzer, D.B.; Hadley, S.W.; Markel, T.; Marnay, C.; Kintner-Meyer, M. (2012). End-Use Electricity Demand. Vol. 3 of Renewable Electricity Futures Study. NREL/TP-6A20-52409-3. Golden, CO: National Renewable Energy Laboratory.

Hsu, J. (2012). Why America's Love Affair with cars is no accident. Retrieved from http://www.scientificamerican.com/article/why-americas-love-affair-cars-no-accident/.

Humana, Inc. (2008). Pedaling A Healthy Initiative: Humana Brings Freewheelin Bike Sharing Effort to U.S. Cities. Retrieved from http://press.humana.com/press-release/current-releases/pedaling-healthy-initiative-humana-brings-freewheelin-bike-sharing-ef.

Inman, M. (2008). Carbon is Forever. Nature Reports Climate Change. Retrieved from http://www.nature.com/climate/2008/0812/full/climate.2008.122.html.

IPCC, Intergovernmental Panel on Climate Change (2014). Climate Change 2014: Synthesis Report Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. IPCC, Geneva, Switzerland.

International Electrotechnical Commission (n.d.). Efficient Electrical Energy Transmission and Distribution. Geneva, Switzerland. Retrieved September 27, 2015 from http://www.iec.ch/about/brochures/pdf/technology/transmission.pdf.

International Energy Agency, IEA (2007). IEA Energy Technology Essentials: Biomass for Power Generation and CHP. Retrieved from https://www.iea.org/publications/freepublications/publication/essentials3.pdf.

Jacobson, M. Z., Bazouin, G., Bauer, Z. A. F., Heavey, C. C., Fisher, E., Hutchinson, E.C., … Yeskoo, T. W. (2014a). 100% Wind, Water, Sunlight (WWS) All-Sector Energy Plans for the 50 United States. Retrieved from http://web.stanford.edu/group/efmh/jacobson/Articles/I/USStatesWWS.pdf.

Jacobson, M. Z., Bazouin, G., Dvorak, M. J., Archandeh, R., Bauer, Z. A. F., Cotte, A. … Yeskoo, T. W. (2014b). A 100% Wind, Water, Sunlight (WWS) All-Sector Energy Plan for Washington State.

Jacobson, M. Z., & Delucchi, M. A., (2009). A Path to Sustainable Energy by 2030. *Scientific American* November 2009, p. 58 – 65.

Jacobson, M. Z. & Delucchi, M. A. (2011). Providing all global energy with wind, water, and solar power, Part I: Technologies, energy resources, quantities and areas of infrastructure, and materials. *Energy Policy* 39 (3) p. 1154-1169. DOI: 10.1016/j.enpol.2010.11.040.

Jacobson, M. Z., Howarth, R. W., Delucchi, M. A., Scobie, S. R., Barth, J. M., Dvorak, M. J. ... Ingraffea, A. R. (2013). Examining the feasibility of converting New York State's all-purpose energy infrastructure to one using wind, water, and sunlight. *Energy* 5, June 2013, p. 585-601.

Jacobson, M. Z., Delucchi. M. A., Ingraffea, A. R., Howarth R. W., Bazouin G., Bridgeland. B.... Yeskoo, T. (2014). A roadmap for repowering California for all purposes with wind, water, and sunlight. *Energy* 73 (14) p. 875-889. DOIi:10.1016/j.energy.2014.06.099.

Kao, S., McManamay, R. A., Stewart, K. M., Smau, N. M., Hadjerioua, B., DeNeale, S. T., Yeasmin, D., Fayzul, M., Pasha, K., Oubeidillah, A. A., & Smith, B. T. (2014). New Stream-reach Development: A Comprehensive Assessment of Hydropower Energy Potential in the United States. U. S. Department of Energy.

Kepton, W., & Tomic J. (2005). Vehicle-to-grid power implementation: From stabilizing the grid to supporting large-scale renewable energy. *Journal of Power Sources* 144 (2005) 280–294.

Kempton, W., & Letendre, S. (1997). Electric Vehicles as a New Power Source for Electric Utilities. *Transportation Research Part D: Transport and Environment*, 2 (3), 157–175.

Kentucky Clean Fuels Coalition (n.d.). University of Louisville Vehicle Deployment and Research. Retrieved January 23, 2016 from http://kentuckycleanfuels.org/electricity/university-louisville-vehicle-deployment-research/.

Kentucky Department of Natural Resources (2008). Kentucky mine mapping awarded best online service. Retrieved from http://migration.kentucky.gov/newsroom/eppc_dnr/KYMineMappingAward2008.htm.

Kentucky Energy and Environment Cabinet, Department of Natural Resources (2014). Kentucky Coal Facts, 14th Edition. Retrieved January 9, 2016 from http://www.kentuckycoal.org/documents/Kentucky%20Coal%20Facts%20-%2014th%20Edition.pdf.

Kentucky Energy and Environment Cabinet, Department of Natural Resources (2016). Kentucky Quarterly Coal Report. Retrieved February 27, 2016 from http://energy.ky.gov/Coal%20Facts%20Library/Kentucky%20Quarterly%20Coal%20Report%20%28Q4-2015%29.pdf.

Kentucky Energy and Environment Cabinet, Department for Energy Development & Independence (n.d.). Kentucky Energy Profile 2014. Retrieved January 9, 2016 from http://energy.ky.gov/Kentucky_Energy_Profile/Kentucky%20Energy%20Profile%202014.pdf.

Kentucky Foundation (n.d.). Kentucky Coal Education: Kentucky History – Coal. Retrieved January 9, 2016 from http://www.coaleducation.org/coalhistory/default_H.htm.

Kentucky Public Service Commission (2012). Direct testimony of John Gant on behalf of Kentucky Industrial Utility Customers and Carbide Industries LLC. Retrieved from http://psc.ky.gov/pscecf/2012-00222/mkurtz@bkllawfirm.com/10032012d/Direct_Testimony_of_John_Gant_%28LGE%29_-_FINAL.pdf.

Kentucky Public Service Commission (2013a). Retrieved from http://psc.ky.gov/UFR_PDF/Electric%5C2013%5C500_Louisville_Gas_and_Electric_Company.pdf.

Kentucky Public Service Commission (2013b). Staff Report on the 2011 Integrated Resource Plan of the Louisville Gas and Electric Company and Kentucky Utilities Company. Case No. 2011-00140.

Kentucky Sustainable Energy Alliance (n.d.). Renewable and Efficiency Portfolio Standard. Retrieved January 23, 2016 from http://www.kysea.org/legislative-policy-work/2011-legislative-goals/renewable-and-efficiency-portfolio-standard.

Kinloch, D. (2010). Land and Energy in Kentucky: Twin Conservation Challenges. Part II: Technical Primer. Kentucky Conservation Committee. Retreived from http://www.kyconservation.org/2009-annualmeeting-report-II.pdf.

Kirchner, T. (2008). Grid Can Handle Rechargeable Cars. *Light & Medium Truck,* 21 (9) 50.

Konrad, T. (2014). How geothermal heat pumps can soar like solar. *Forbes*. Retrieved from http://www.forbes.com/sites/tomkonrad/2014/02/28/how-geothermal-heat-pumps-can-soar-like-solar/.

Lambert, S. C. (2008). Renewable Energy Resource Inventory in Kentucky. Slide presentation given to the Kentucky Sustainable Energy Alliance.

Lane Report (2015). New financing program offers energy efficient options. Retrieved from http://www.lanereport.com/46554/2015/03/new-financing-program-offers-energy-efficient-options/.

Laplante, J. & McCann, B. (2008). Complete Streets: We Can Get There from Here. *ITE Journal*. 78.5: 24-28. Retrieved from http://search.proquest.com.ezp-prod1.hul.harvard.edu/docview/224879686/fulltextPDF/4AD1A961148C4044PQ/1?accountid=11311.

Lazar, J. (2014). Teaching the "Duck" to Fly. Montpelier, Vermont: RAP Publications.

League of American Bicyclists (2015). News from the League. BFC Spotlight: Louisville. Retrieved from http://bikeleague.org/content/bfc-spotlight-louisville.

Lee, J. (2014). The effects power outages can have on your computer. Retrieved from http://www.makeuseof.com/tag/effects-power-outages-can-computer/.

Legiscan (2015). Kentucky Senate Bill 196. Retrieved from https://legiscan.com/KY/bill/SB196/2015.

Linden, M. (2015). Tesla supercharging station opens in Lexington; first in Kentucky. WKYT. Retrieved from http://www.wkyt.com/home/headlines/Tesla-supercharging-station-opens-in-Lexington-first-in-Kentucky-291311721.html.

Li, S., Yoo, H.K., Shih, J., Palmer, K. & Macauley, M. (2014). Assessing the Role of Renewable Energy Policies in Landfill Gas Energy Policies.

Liu, C., Chau, K.T., Wu, D., & Gao, S. (2013). Opportunities and Challenges of Vehicle-to-Home, Vehicle-to-Vehicle, and Vehicle-to-Grid Technologies. *Proceedings of the IEEE* 101 (11).

Lopez, A., Roberts, B., Heimiller, D., Blair, N., & Porro, G. (2012). U.S. Renewable Energy Technical Potentials: A GIS-Based Analysis. National Renewable Energy Laboratory. Retrieved from http://www.nrel.gov/docs/fy12osti/51946.pdf.

Louisville Gas and Electric Company, LG&E (2015). Our Company. Retrieved August 29, 2015 from https://lge-ku.com/our-c http://www.ciosummits.com/media/pdf/solution_spotlight/sas_forecasting-enhance-smart-grid.pdfompany.

Louisville Gas and Electric Company, LG&E (2014). Power Plant Information. Retrieved from http://lge-ku.com/plant_info.asp.

Louisville Gas and Electric Company, LG&E (n.d.a). Saving Energy & Money. Retrieved August 29, 2015 from https://lge-ku.com/saving-energy-and-money.

Louisville Gas and Electric Company, LG&E (n.d.b). Home Energy Rebates. Retrieved April 21, 2016 from https://lge-ku.com/saving-energy-money/home-energy-rebates.

Louisville Metro Government (2013). Sustain Louisville: Louisville Metro Sustainability Plan. Retrieved from http://louisvilleky.gov/sites/default/files/sustainability/pdf_files/sustainlouisville.pdf.

Louisville Metro Public Works (n.d.). Central Business District Wet-Dry Recycling. Retrieved December 28, 2015 from https://louisvilleky.gov/government/public-works/central-business-district-wet-dry-recycling.

Louisville Regional Airport Authority (n.d.). Electric Vehicle Charging Now Available. Retrieved February 23, 2016 from http://www.flylouisville.com/electric-vehicle-charging-now-available/.

Lovins, A. (2007). "Implications for Energy Efficiency," lecture at Stanford University, 30 March 2007. Retrieved from http://csi.gsb.stanford.edu/node/11576/download/SI.EN-AmoryLovinsIX-2007.03.30.mp3.

Lund, J., Sanner, B., Rybach, L., Curtis, R. & Hellstrom, G. (2004). Geothermal (ground0source) heat pumps a world review. GHC Bulletin. Retrieved from http://file.seekpart.com/keywordpdf/2011/5/24/2011524112558636.pdf.

Mai, T.; Sandor, D.; Wiser, R.; Schneider, T (2012a). Renewable Electricity Futures Study: Executive Summary. NREL/TP-6A20-52409-ES. Golden, CO: National Renewable Energy Laboratory.

Mai, T.; Wiser, R.; Sandor, D.; Brinkman, G.; Heath, G.; Denholm, P.; Hostick, D.J.; Darghouth, N.; Schlosser, A.; Strzepek, K. (2012b). Exploration of High-Penetration Renewable Electricity Futures. Vol. 1 of Renewable Electricity Futures Study. NREL/TP-6A20-52409-1. Golden, CO: National Renewable Energy Laboratory.

Mardookhy, M., Sawhney, R., Ji, S., Zhu, X., & Zhou, W. (2014). A study of energy efficiency in residential buildings in Knoxville, Tennessee. *Journal of Cleaner Production* 85 (2014) 241-249.

Martin, C. & Crawford, J. N. (2015). California power grid seen to able handle 100% renewable. *Bloomberg Business.* Retrieved from http://www.bloomberg.com/news/articles/2015-04-14/california-power-grid-seen-able-to-handle-100-renewables.

Martin, R. (2013). Installed Capacity of Geothermal Heat Pumps Will Grow by Nearly 150 Percent by 2020. Navigant Research. Retrieved from https://www.navigantresearch.com/newsroom/installed-capacity-of-geothermal-heat-pumps-will-grow-by-nearly-150-percent-by-2020.

Maxwell Technologies (n.d.). Energy Solutions for the Grid. Retrieved from http://issuu.com/maxwelltechnologies/docs/energy_storage_brochure_3000957-en./11?e=14613819/13114628

McKenzie, N. (2014). Modes less traveled – Bicycling and walking to work in the United States: 2008- 2012. American Commuter Survey United States Census Bureau.

Melius, J., Margolis, R., & Ong, S. (2013). Estimating Rooftop Suitability for PV: A review of methods, patents, and validation techniques. National Renewable Energy Lab. Retrieved from http://www.nrel.gov/docs/fy14osti/60593.pdf.

Milbrandt, A. (2005). A Geographic Perspective on the Current Biomass Resource Availability in the United States. National Renewable Energy Laboratory. Retrieved from http://www.nrel.gov/docs/fy06osti/39181.pdf.

Milligan, M.; Ela, E.; Hein, J.; Schneider, T.; Brinkman, G.; & Denholm, P. (2012). Exploration of High-Penetration Renewable Electricity Futures. Vol. 4 of Renewable Electricity Futures Study. NREL/TP-6A20-52409-4. Golden, CO: National Renewable Energy Laboratory.

Mims, N., Bell, M. & Doig, S. (2009). "Assessing the Electric Productivity Gap and the U.S. Efficiency Opportunity."

Mog, J. (2016). U of L is committed to building smarter and conserving energy and water on campus. Buildings & Energy. Retrieved from http://louisville.edu/sustainability/operations/buildings-energy.html.

Molina, W. G. (2010). Dynamic Modeling and Control Design of Advanced Energy Storage for Power System Applications. Croatia. Retrieved from http://cdn.intechopen.com/pdfs-wm/6820.pdf.

Morales, A. (2014). Fossil fuels with $550 billion subsidies hurt renewable. Bloomberg Business, November 12, 2014. Retrieved from http://www.bloomberg.com/news/articles/2014-11-12/fossil-fuels-with-550-billion-in-subsidy-hurt-renewables.

Musk, E. (2015). Retrieved from https://twitter.com/elonmusk/status/594186544174366720.

National Grid (n.d.). Retrieved from https://commons.wikimedia.org/wiki/File:Demand_graph.jpg.

Nelder, C. (2013). Turn Up the Juice: New Flywheel Raises Hopes for Energy Storage Breakthrough. *Scientific American*, April10, 2013. Retrieved from http://www.scientificamerican.com/article/new-flywheel-design/.

NERC, North American Electric Reliability Corporation (2015). Proposed revisions to the glossary of terms. Retrieved from http://www.nerc.com/pa/Stand/Project201504AlignmentofGlossaryofTermsNERCSRPDL/Project_2015-04-Glossary_revisions_redline_06102015.pdf.

NREL, National Renewable Energy Labs (2015a). Biomass Maps. Retrieved from http://www.nrel.gov/gis/biomass.html.

NREL, National Renewable Energy Labs (2015b). State and Local governments: Renewable Portfolio Standards. Retrieved from http://www.nrel.gov/tech_deployment/state_local_governments/basics_portfolio_standards.html.

National Resources Defense Council (2005). A Responsible Energy Plan for America. Retrieved from http://physics.gac.edu/~huber/classes/FTS100/nrdc_report_2005.pdf.

Nordelof, A., Messagie, M., Tillman, A., Siderman, M., & Van Mierlo, J. (2013). Environmental impacts of hybrid, plug-in hybrid, and batter electric vehicles - what can we learn from life cycle assessment? International Journal of Live Cycle Assessments (2014) 19:1866-1890. DOI: 10.1007/s11367-014-0788-0.

O'Neil, T. (2013). LG&E, KU plan new gas plant, small solar generator. *The Courier-Journal,* October 10, 2013. Retrieved from http://www.courier-journal.com/story/tech/science/environment/2013/10/03/lge-ku-plan-new-gas-plant-small-solar-generator/2915553/.

On the Issues (2015). Matt Bevin on Energy & Oil. Retrieved from http://www.ontheissues.org/Governor/Matt_Bevin_Energy_+_Oil.htm.

Pacala, S., & Socolow, R. (2004). Stabilization Wedges: Solving the Climate Problem for the Next 50 Years with Current Technologies. *Science* Vol. 305, pages 968–972. doi: 10.1126/science.1100103.

Patrick, A., Blanford, A., Waddell, & A. James (2014). Kentucky Coal Facts, 14th Edition. Retrieved from http://energy.ky.gov/Coal%20Facts%20Library/Kentucky%20Coal%20Facts%20-%2014th%20Edition%20%282014%29.pdf.

Pedersen, E. & Waye, K. P. (2007). Wind turbine noise, annoyance and self-reported health and well-being in different living environments. *Occupational Environmental Medicine.* 64 (7) p. 480-486. DOI: 10.1136/oem.2006.031039.

PFPI, Partnership for Policy Integrity (2011). Biomass energy overview. Retrieved from http://www.pfpi.net/biomass-basics-2.

Pohlman, D. (2013). Images: Dixie Highway Improvement Project renderings. WLKY. Retrieved from http://www.wlky.com/news/local-news/louisville-news/images-dixie-highway-improvement-project-renderings/23454636.

PowerSouth Energy Cooperative (n.d.). CAES. Retrieved September 6, 2015 from http://www.powersouth.com/mcintosh_power_plant/compressed_air_energy.

PRI (2012). Sweden imports waste from European neighbors to fuel waste-to-energy program. Retrieved from http://www.pri.org/stories/2012-06-26/sweden-imports-waste-european-neighbors-fuel-waste-energy-program.

PR Newswire (2014). Flywheel Energy Storage Market Growing at 21% CAGR Globally to 2018. Retrieved from http://www.prnewswire.com/news-releases/flywheel-energy-storage-market-growing-at-21-cagr-globally-to-2018-281928001.html.

PR Newswire (2015). Kentucky Municipal Power Company Uses Sunverge Energy Storage Systems for Innovative Demand Response Program. Retrieved from http://www.prnewswire.com/news-releases/kentucky-municipal-power-company-uses-sunverge-energy-storage-systems-for-innovative-demand-response-program-300128618.html.

Project Finance (2014). Japan's feed-in tariff sparks solar PV boom. Retrieved from https://ijglobal.com/pf-archive/article/3302603/japans-feed-in-tariff-sparks-solar-pv-boom.

ProximityOne (n.d.). Demographic Trends: Population Estimates & Projections for U.S., States, Metros & Counties 2010-2060. Retrieved January 19, 2016 from http://proximityone.com/demographics2060.htm.

Radulovic, D., Skok, S., Kirincic, V. (2011). Energy efficiency public lighting management in the cities. *Energy* 34 (4) 1908-1915.

Rare Earth Technology Alliance (n.d.). What are rare earths? Retrieved from http://www.rareearthtechalliance.com/What-are-Rare-Earths.

Rashid, N. (2011). Short-time Overloading of Power Transformers. Master Thesis Royal Institute of Technology, June 2011. Retrieved from http://www.diva-portal.se/smash/get/diva2:511551/FULLTEXT01.pdf.

Recast Energy, LLC. (n.d.). Biomass. Retrieved January 4, 2016 from http://www.recastenergy.com/Biomass/biomass.html.

Romm, J. J. & Browning, W. D. (n.d.). Greening the building and the bottom line: Increasing productivity through energy-efficient design. Rocky Mountain Institute.

Roth, S. (2014). Palen solar project dropped by developers. *The Desert Sun.* Retrieved from http://www.desertsun.com/story/tech/science/energy/2014/09/26/palen-solar-plant-developers/16294531/.

Russell, J. (2015). Tesla's $3,000 Powerwall will let households run entirely on solar energy. Tech Crunch Daily. Retrieved from http://techcrunch.com/2015/04/30/tesla-powerwall-home-battery/#.jm1eoi:MSfB.

Ryan, Jacob (2015). Louisville's Bike Share Program Probably Won't Launch Until 2016. WFPL. Retrieved from http://wfpl.org/louisvilles-bike-share-program-probably-wont-launch-2016/.

SAS Institute, Inc. (n.d.). How does forecasting enhance smart grid benefits? Retrieved from http://www.ciosummits.com/media/pdf/solution_spotlight/sas_forecasting-enhance-smart-grid.pdf.

Sawin, J. L. & Moomaw, W. R. (2009). Worldwatch Report. Renewable Revolution: Low-Carbon Energy by 2030. Worldwatch Institute.

Saxena, S., Le Floch, C., MacDonald, J., & Moura, S. (2014). Quantifying EV battery end-of-life through analysis of travel needs with vehicle powertrain models. *Journal of Power Sources* 282 (2015) 265-276.

Saxton, T. (2011). Plug In America. Understanding electric vehicle charging. Retrieved from http://www.pluginamerica.org/drivers-seat/understanding-electric-vehicle-charging.

Scanlan, D. (2015). 28 new electric car charging stations to begin construction in Jacksonville are next month. *The Florida Times-Union*. Retrieved from http://jacksonville.com/news/transportation/2015-09-18/story/28-new-electric-car-charging-stations-begin-construction.

Searchinger, T. & Heimlich, R. (2015). Avoiding Bioenergy Competition for Food Crops and Land. World Resources Institute. Retrieved from http://www.wri.org/publication/avoiding-bioenergy-competition-food-crops-and-land.

Searchinger, T., Heimlich, R., Houghton, R.A., Dong, F., Elobeid, A., Fabiosa, J., Tonkgoz, S., Hayes, D., & Tun-Hsiang, Y. (2005). Use of U.S. Croplands for

Biofuels Increases Greenhouse Gases Through Emissions from Land-Use Change. *Science* (319) 5867, p. 1238-1240. DOI: 10.116/science.1151861.

Shepherd, D., McBride, D., Welch, D., Dirks, K.N., Hill, E.M. (2011). Evaluating the impact of wind turbine noise on health-related quality of life. *Noise Health.* Retrieved from: http://www.noiseandhealth.org/text.asp?2011/13/54/333/85502.

Short, W.; Sullivan, P.; Mai, T.; Mowers, M.; Uriarte, C.; Blair, N.; Heimiller, D.; Martinez, A. (2011). Regional Energy Deployment System (ReEDS). National Renewable Energy Laboratory. Retrieved from http://www.nrel.gov/docs/fy12osti/46534.pdf.

Silver Spring Networks (2013). How the Smart Grid Enables Utilities to Integrate Electric Vehicles. Retrieved from http://www.silverspringnet.com/pdfs/whitepapers/SilverSpring-Whitepaper-ElectricVehicles.pdf.

Smart Growth America (n.d.). National Complete Streets Coalition. Retrieved from http://www.smartgrowthamerica.org/complete-streets.

Smithsonian Institute (n.d.). Generating Electrons. Retrieved September 17, 2015 from http://americanhistory.si.edu/powering/generate/gnmain.htm.

SRU, German Advisory Council on the Environment (2010). Climate-friendly, reliable, affordable: 100% renewable electricity supply by 2050.

St. John, J. (2013). Ultracapacitors provide solar-to-grid smoothing in San Diego. Greentech Media. Retrieved from http://www.greentechmedia.com/articles/read/Ultracapacitors-Provide-Solar-to-Grid-Smoothing-in-San-Diego.

Su, W., Rahimi-Eichi, H., Zeng, W., & Chow, M. (2012). A survey on the electrification of transportation in a smart grid environment. *IEEE Transactions on Industrial Informatics*, 8(1) 1-10.

SuperPower, Inc. (n.d.). Superconducting magnetic energy storage. Retrieved December 4, 2015 from http://www.superpower-inc.com/content/superconducting-magnetic-energy-storage-smes.

Taylor, B. D., & Fink, C. N. Y. (2003). The factors influencing transit ridership: a review and analysis of the ridership literature. UCLA Institute of Transportation Studies. Los Angeles, CA.

TVA, Tennessee Valley Authority (n.d.). Green Power Providers. Retrieved January 23, 2016 from https://www.tva.com/Energy/Renewable-Energy-Solutions/Green-Power-Providers.

Tesla Motors (n.d.a). Powerwall Home Battery. Retrieved February 5, 2016 from https://www.teslamotors.com/powerwall.

Tesla Motors (n.d.b). Tesla Energy. Retrieved February 28, 2016 from https://www.teslamotors.com/presskit/teslaenergy.

Tesla Motors (n.d.c). Supercharger. Retrieved March 13, 2016 from https://www.teslamotors.com/supercharger.

Tessum, C., Hill, J. D., & Marshall, J. D. (2014). Life cycle air quality impacts of conventional alternative light-duty transportation in the United States. *Proceedings of the National Academy of Sciences of the United States of America* 111(52) 18490-18495.

Tilman, D., Socolaw, R., Foley, J., Hill, J., Larson, E., Lynd, L., … Williams, R. (2009). Beneficial Biofuels—The Food, Energy, and Environment Trilemma, *Science*, 325, 270-271.

Toncray, M. (2012). The Independent Ledger. Mason County considered for hydropower project. Retrieved from http://www.maysville-online.com/news/mason-county-considered-for-hydropower-project/article_df00a8b8-be64-5323-901e-f1a2d4b7a142.html.

Trabish, H. K. (2014). Smart inverters: The secret to integrating distributed energy onto the grid?: Utilities and research teams are taking distributed energy solutions to the wires. Utility Dive. Retrieved from http://www.utilitydive.com/news/smart-inverters-the-secret-to-integrating-distributed-energy-onto-the-grid/269167/.

TARC, Transit Authority of River City (n.d.). What is the Zero Bus? Retrieved January 12, 2016 from http://www.ridetarc.org/internalonecolumn.aspx?id=1485.

TARC, Transit Authority of River City (2008). Long Range Plan Update 2008-2009. Retrieved from https://www.ridetarc.org/uploadedFiles/About_TARC/Long_Range_Plan/Long%20Range%20Plan.pdf.

Trinity Consultants and Louisville Metro Air Pollution Control District (2008). *Greenhouse Gas Emissions Inventory Report Louisville/Jefferson County Metro Government*. Louisville, Kentucky.

U.S. Conference of Mayors (2005). U.S. Conference of Mayors Climate Protection Agreement. Retrieved from http://www.usmayors.org/climateprotection/agreement.htm.

U. S. Department of Agriculture (2015). Census of Agriculture. 2012 Census Volume 1, Chapter 2: County Level. Retrieved from http://www.agcensus.usda.gov/Publications/2012/Full_Report/Volume_1,_Chapter_2_County_Level/Kentucky/st21_2_011_011.pdf.

U.S. Department of Commerce, Census Bureau. (n.d.a). Selected Housing Characteristics, 2009-2012 American Community Survey 5-Year Estimates. Retrieved November 12, 2015 from http://factfinder2.census.gov/faces/tableservices/jsf/pages/productview.xhtml?src=bkmk.

U. S. Department of Commerce, Census Bureau. (n.d.b.). 2005-2009 American Community Survey, Aggregate Number of Vehicles Available by Tenure. Retrieved November 12, 2015 from http://factfinder.census.gov/faces/tableservices/jsf/pages/productview.xhtml?pid=ACS_09_5YR_B25046&prodType=table.

U. S. Department of Commerce, Census Bureau. (n.d.c.). 2009-2013 American Community Survey, Aggregate Number of Vehicles Available by Tenure. Retrieved November 12, 2015 from http://factfinder.census.gov/faces/tableservices/jsf/pages/productview.xhtml?pid=ACS_13_5YR_B25046&prodType=table

U. S. Department of Commerce, Census Bureau (n.d.d.). Metropolitan and Micropolitan: Other metropolitan and micropolitan statistical area resources. Retrieved September 22, 2015 from http://www.census.gov/population/metro/data/other.html

U. S. Department of Energy (n.d.). Geothermal heat pumps. Retrieved December 16, 2015 from http://energy.gov/energysaver/geothermal-heat-pumps.

U. S. Department of Energy (n.d.). Air-source heat pumps. Retrieved January 22, 2016 from http://energy.gov/energysaver/air-source-heat-pumps.

U. S. Department of Energy (n.d.). Heat pump systems. Retrieved January 23, 2016 from http://energy.gov/energysaver/heat-pump-systems.

U. S. Department of Energy (2002). Electric Utility Demand-Side Management 2000. Retrieved from http://www.eia.gov/electricity/data/eia861/dsm/058900.pdf.

U. S. Department of Energy (2004). State Energy Program Case Studies: California Says “Go” to Energy-Saving Traffic Lights. Retrieved from http://www.nrel.gov/docs/fy04osti/35551.pdf.

U. S. Department of Energy (2007). U.S. Energy Requirements for Aluminum Production: Historical Perspective, Theoretical Limits and Current Practices.

Retrieved from http://www1.eere.energy.gov/manufacturing/resources/aluminum/pdfs/al_theoretical.pdf.

U. S. Department of Energy (2009). National Electric Transmission Congestion Study.

U. S. Department of Energy (2012a). SunShot Vision Study. Retrieved from http://www1.eere.energy.gov/solar/pdfs/47927.pdf.

U. S. Department of Energy (2012b). The New Energy Saver.gov – Save money by saving energy. Retrieved from http://energy.gov/articles/new-energysavergov-save-money-saving-energy.

U. S. Department of Energy (2013). Grid Energy Storage. Retrieved from http://www.sandia.gov/ess/docs/other/Grid_Energy_Storage_Dec_2013.pdf.

U. S. Department of Energy (2014a). Alternative Fuels Data Center. Retrieved September 23, 2015 from http://www.afdc.energy.gov/data/.

U. S. Department of Energy, Office of Electricity Delivery & Energy Reliability (n.d.a). Smart Grid. Retrieved November 29, 2015 from http://energy.gov/oe/services/technology-development/smart-grid.

U. S. Department of Energy, Office of Energy Efficiency & Renewable Energy (n.d.b). Spring and Summer Energy-Saving Tips. Retrieved April 19, 2016 from http://energy.gov/energysaver/spring-and-summer-energy-saving-tips.

U. S. Department of Energy and U. S. Environmental Protection Agency (2014). www.fueleconomy.gov, All-Electric Vehicles: Compare Side-by-Side. Retrieved from http://www.fueleconomy.gov/feg/evsbs.shtml.

U. S. Department of Transportation, Federal Highway Administration, Policy Information, Highway Finance Date & Information (n.d.). Retrieved from http://www.fhwa.dot.gov/policyinformation/pubs/pl08021/fig3_1.cfm.

U. S. Department of Transportation, Federal Highway Administration (2015). Alternative Uses of Highway Right-of-Way. Retrieved from http://www.fhwa.dot.gov/real_estate/publications/alternative_uses_of_highway_right-of-way/rep03.cfm#tbl2.

U. S. Energy Information Administration, EIA (2014a). Today in Energy. Half of power plant capacity additions in 2013 came from natural gas. Retrieved from http://www.eia.gov/todayinenergy/detail.cfm?id=15751.

U. S. Energy Information Administration, EIA (2014b). Energy in Brief. How much of the U.S. electricity supply come from wind and how does that compare with other countries? Retrieved from http://www.eia.gov/energy_in_brief/article/wind_power.cfm.

U. S. Energy Information Administration, EIA (2015a). Frequently Asked Questions: How much electricity does an American home use? Retrieved from http://www.eia.gov/tools/faqs/faq.cfm?id=97&t=3.

U. S. Energy Information Administration, EIA (2015b). State Profile and Energy Estimates. Retrieved from http://www.eia.gov/state/?sid=KY.

U. S. Energy Information Administration, EIA (2015c). Frequently Asked Questions: How much electricity is lost in transmission in the United States? Retrieved from http://www.eia.gov/tools/faqs/faq.cfm?id=105&t=3.

U. S. Energy Information Administration, EIA (2015d). Annual energy outlook 2015 with projections to 2040. Retrieved from http://www.eia.gov/forecasts/aeo/pdf/0383%282015%29.pdf.

U. S. Energy Information Administration, EIA (2015d). Short-term Energy Outlook: Renewable and CO2 Emissions. Retrieved from https://www.eia.gov/forecasts/steo/report/renew_co2.cfm.

U. S. Energy Information Administration, EIA (2015f). Electricity Power Monthly. Retrieved from http://www.eia.gov/electricity/monthly/.

U. S. Environmental Protection Agency, EPA (2016a). Overview of Greenhouse Gases. Retrieved from http://www3.epa.gov/climatechange/ghgemissions/gases/ch4.html.

U. S. Environmental Protection Agency, EPA (2016b). State Energy CO_2 Emissions. Retrieved from http://www3.epa.gov/statelocalclimate/resources/state_energyco2inv.html.

U. S. Environmental Protection Agency, EPA (2015a). Livestock Anaerobic Digester Database. Retrieved from http://www.epa.gov/agstar/livestock-anaerobic-digester-database.

U. S. Environmental Protection Agency, EPA (2015b). Local Examples of Climate Action. Retrieved from http://www3.epa.gov/statelocalclimate/local/local-examples.html.

U. S. Environmental Protection Agency, EPA (2015c). U.S. Greenhouse Gas Inventory Report: 1990-2013. Retrieved from http://www.epa.gov/climatechange/ghgemissions/usinventoryreport.html.

U. S. Energy Information Administration (2015e). Short-term Energy Outlook. Retrieved from https://www.eia.gov/forecasts/steo/report/electricity.cfm.

U. S. Environmental Protection Agency, EPA (2014). Green Power Market. Retrieved from http://www.epa.gov/greenpower/gpmarket/.

U. S. Environmental Protection Agency, EPA (2014). Interactive Conversion Tool. Retrieved from http://www.epa.gov/lmop/projects-candidates/interactive.html.

U. S. Environmental Protection Agency, EPA (2013). State of the National LFG Industry. An Overview of Landfill Gas Energy in the United States. Retrieved from http://www3.epa.gov/lmop/documents/pdfs/overview.pdf.

Union of Concerned Scientists (2015, December 24). Rooftop Solar Panels: Benefits, Costs, and Smart Policies. Retrieved from http://www.ucsusa.org/clean-energy/renewable-energy/rooftop-solar-panels-benefits-costs-policies.

Van der Bossche, P., Vergels, F., Van Mierlo, J., Matheys, J., & Van Autenboer, W. (2005). SUBAT: An assessment of sustainable battery technology. *Journal of Power Sources* 162 (2006) 913-919.

Velkess (n.d.). Velkess Now Taking Orders for Revolutionary Energy Storage Products. Retrieved December 6, 2015 from http://www.velkess.com/velkess-now-taking-orders-for-revolutionary-energy-storage-products/.

Vidal, O., Goffé, B., & Arndt, N. (2013). Metals for a low-carbon society. *Nature Geoscience*, Vol. 6, p. 894-6.

Wang, C., & Nehrir, M. H. (2008). Power Management of a Stand-Alone Wind/Photovoltaic/Fuel Cell Energy System *IEEE Transactions on Energy Conversion*, 23(3), 957-967.

Watson, R. L., Gyenes, L. & Armstrong, B. D. (1986). A Refueling Infrastructure for an All-Electric Car Fleet. Transport and Road Research Laboratory, Department of Transport, Crowthorne, Berkshire, England.

Wei, M., Nelson, J.H., Greenblatt, J.B., Mileva, A., Johnston, J., Ting, M., … Kammen, D.M. (2013). Deep carbon reductions in California require electrification and integration across sectors. *Environ Research Letters* 2013; 8:014038. DOI: 10.1088/1748-9326/8/1/014038.

Websolar.com (n.d.). Renesola 310W Polycrystalline Solar Panel. Retrieved April 11, 2016 from http://webosolar.com/store/en/grid-tie-solar-panels/1552-renesola-310w-polycristalline-solar-panel-jc310m-24-ab.html

Weliczko, E. (2013). Tracking Your Energy Use With Home Monitoring Systems. *Home Power* Issue 153, February/March 2013. Retrieved from http://www.homepower.com/articles/home-efficiency/electricity/tracking-your-energy-use.

Wiese, S., Libby, L., Long, E., & Ryan, B. (2010). A solar rooftop assessment for Austin. *SOLAR 2010 conference proceedings*.

Williams, C. (2012). New 10 Year $.12kWh TVA Solar PV Feed in Tariff –> Requires NABCEP Solar PV Entry Level Certification. *HeatSpring Magazine.* Retrieved from https://blog.heatspring.com/tva-solar/.

Wilson, A., & Wendt, A. (2007). The Challenge of Existing Homes: Retrofitting for Dramatic Energy Savings. *Environmental Building News* 16 (7). Retrieved from https://www2.buildinggreen.com/article/challenge-existing-homes-retrofitting-dramatic-energy-savings.

Winemiller, K. O., McIntyre, P. B., Castello, L., Fluet-Chouinard, E., Giarrizzo, T., Nam, S., Baird, I. G., Darwall, W., Lujan, N. K., Harrison, I., Stiassny, M. L. J., Silvano, R. A. M., Fitzgerald, D. B., Pelicice, F. M., Agostinho, A. A., Gomes, L. C., Albert, J. S., Baran, E., Petrere M., Zarfl, C., Mulligan, M., Sullivan, J. P., Arantes, C. C., Sousa, L. M., Koning, A. A., Hoeinghaus, D. J., Sabaj, M., Lundberg, J. G., Armbruster, J., Thieme, M. L., Petry, P., Zuanon, J., Torrente, G., Vilara, G., Snoeks, J., Ou, C., Rainboth, W., Pavanelli, C. S., Akama, A., van Soesbergen, A., Sáenz, L.(2016). Balancing hydropower and biodiversity in the Amazon, Congo, and Meking. *Science* 351 (6269), p. 128-9. Doi:10.1126/science.aac7082.

Wu, X., Yao, W. Zhu, J., & Miller, C. (2010). Biogas and CH4 productivity by co-digesting swine manure with three crop residues as an external carbon source. *Bioresource Technology* 101 (11) p. 4024-4047. Doi:10.1016/j.biortech.2010.01.052.

Yiridoe, E. K., Gordon, R., & Brown, B. B. (2009). Nonmarket cobenefits and economic feasibility of on-farm biogas energy production. *Energy Policy* 37 p. 1170-1179.